ASPECTS OF AIR POLLUTION CLIMATOLOGY IN THE KUALA LUMPUR - PETALING JAYA AREA, MALAYSIA

A thesis submitted to the
University of Canterbury
in fulfilment of the
requirements for the Degree
of Doctor of Philosophy

Sham Sani

1977

Abstract

Five explicit objectives were established for this study of air pollution climatology in the Kuala Lumpur - Petaling Jaya area. They were: (1) to describe the local climate of the area and its likely implications on air pollution; (2) to examine the rate and nature of emissions occurring in the study area; (3) to attempt to establish the general level of concentrations of selected pollutants; (4) to investigate the influence of local weather factors on pollution concentration and dispersion; and (5) to examine the possible impact of air pollution and urbanization on climatic parameters.

Data were collected in Malaysia during 1975-76. Total fuels supplied by the various oil companies were used to estimate air pollution emissions; the Factory and Machinery Department supplied data on dustfall at Batu Caves and the SO_2 in Petaling Jaya. Respirable dust particulates were obtained using the gravimetric dust sampler. Along with the Weld Reservoir Station which was set up specifically for the study, climate data were provided by the Meteorological Service, the Drainage and Irrigation Department, and the University of Malaya.

Analyses of these data showed that: (1) On the basis of standard application of U.S. derived forecasting technique, the Kuala Lumpur - Petaling Jaya climate had a great potential for air pollution; (2) Transport, particularly motor vehicles, and industries represent the two most important sources of air pollution. Together they produce 99.3 percent of the major pollutant emissions. Emissions from aircraft, tin mining activitie

and waste disposals are relatively insignificant. This, and examination of pollutants emitted suggests that Kuala Lumpur - Petaling Jaya is subject to the Los Angeles type pollution; (3) Computation of total emissions and comparison of these figures with those obtained from other cities suggests that pollution in the study area is of the same order as low to moderately polluted mid-latitude cities. However marked increases in energy use have occurred recently. This, coupled with climate which is characteristically high in air pollution potential, is certainly a cause for concern; (4) Levels of measured air pollution vary in seriousness from one locality to another within the study area. The average concentration of dustfall in Batu Caves area already far exceeded the standard recommended for residential and light industrial areas. Indeed, some stations had even exceeded that recommended for heavy industrial regions. The monthly values of SO_2 at and around the Malayan Acid Works in Petaling Jaya had also on occasions exceeded the accepted levels for human health and vegetation. In both cases, the distribution appears to be related to prevailing wind direction; in the case of SO_2, scavenging effect from precipitation is also significant in reducing concentration; (5) Respirable dust particulate concentrations vary within the study area. In the centre of Kuala Lumpur and in industrial area of Petaling Jaya, these are relatively high. Contrary to results obtained in several mid-latitude cities, seasonal variations and episodic type occurrences of pollution are not evident in Kuala Lumpur. The influence of weather factors upon respirable dust particulates is largely inconclusive; and (6) Like many large urban areas, Kuala Lumpur - Petaling Jaya has a considerable impact upon [illegible] climate; the degree to which this influences climatic parameters however varies with each climatic variable.

Table of Contents

List of Tables

List of Figures

List of Plates

List of Symbols

Roman Capital Letters

D	Surface dewpoint
L.S.T.	Local standard time
L.T.	Local time
LW	Longwave radiation
LW↓	Longwave radiation towards the surface
LW↑	Longwave radiation from the surface
Q	Direct beam shortwave radiation
R_n	Net all wave radiation
R.H.	Relative humidity
S.D.	Sunshine duration
S.E.E.	Standard error of estimate in regression equation
SW	Shortwave radiation
SW↓	Shortwave radiation towards the surface
SW↑	Shortwave radiation from the surface
T	Temperature
T_r	Atmospheric transmissivity to direct beam radiation

Roman Lower Case Letters

a	Constant in regression equation
b	Constant in regression equation
d	Dust particles
e	Saturation vapour pressure
m	Optical air mass
p	Air pressure
a.m.s.l.	Above mean sea level

k.p.h.	Kilometers per hour
m.p.h.	Miles per hour
p.p.m.	Parts per million
q	Diffuse beam shortwave radiation
r	Simple linear correlation coefficient
t	Value as test statistic
w	Water vapour

Greek Lower Case Letters

α	Alpha, albedo

Units of Measurements

$\mu g/m^3$	Microgram per cubic meter
$mwhr/cm^2$	Milliwatt hour per square centimeter
ms^{-1}	Meter per second (unit of wind speed)

Glossary of Malay Terms

Alam sekitar	-	Environment
Bukit (Bt.)	-	Hill
Gunong (g)	-	Mountain
Jabatan	-	Department
Jalan	-	Road, street
Kementerian	-	Ministry
Negara	-	National
Perancang	-	Planning
Sungai (Sg.)	-	River
Ulu	-	Up-stream

Acknowledgements

The completion of a thesis such as this inevitably requires the cooperation and assistance of a very great number of people. It would be impossible to list out separately all those who have helped with this research. Some individuals and institutions, however, need special mentions and must be thanked by names.

First, I wish to express my sincere gratitude to my supervisor, Dr. I.F. Owens, whose constructive criticisms at the manuscript stage was invaluable. My very special thanks must also go to Professor W.B. Johnston, Head of the Geography Department, University of Canterbury, for initial stimulus to attempt doctoral research, and Dr. D.E. Greenland, INSTAAR, University of Colorado, Boulder, U.S.A. for assistance and encouragement during the initial planning stage.

Second, I wish to express my sincere gratitude to the National University of Malaysia for granting me leave in undertaking this project and financial assistance for enabling the family to come to New Zealand during 1976-77. I am also grateful to En. Abdul Samad Abdul Hadi, who, as Head of the Geography Department, National University of Malaysia, give me full use of the facilities of the Department during the course of the fieldwork, and helped in more ways than one with administrative matters.

Assistance whilst in the field was given by many people too numerous to mention; however, my very special thanks must go to En. Mustapha, En. Abdul Karim (laboratory technicians), En. Kasah (photographic technician), En. Zulkifli, En. Kamil, Syed (cartographic technicians), En. Shah (map librarian), Cik Noraini, Cik Maria, and Cik Shadidah, all of the Geography Department at

Kuala Lumpur, who provided much assistance throughout the course of field data collection and analyses. I am also greatly indebted to the numerous Stage II and III Geography students (1975-76 & 1976-77 sessions) of the National University of Malaysia who helped with the climate surveys and the respirable dust sampling exercises. To these individuals I regret that I cannot show my gratitude in a more tangible form.

Many organizations and individuals played a vital role in facilitating collection of the data required for the study. In this connection I wish to record my sincere and most grateful thanks to the following: The Malaysian Meteorological Service; the Drainage and Irrigation Department, Malaysia; the Factory and Machinery Department, Malaysia; the Chemistry Department Malaysia; the Petaling Jaya Town Board; the Kuala Lumpur City Hall; the Department of Planning Malaysia; the Ministry of Transport Malaysia; the Central Electricity Board Malaysia; the Geography Department, University of Malaya; the Shell Oil Company; the B.P. Oil Company; the Caltex Oil Company; the Mobil Oil Company; and the Esso Oil Company. Sincere thanks are also due to the General Managers of the Central Electricity Board, the Selangor State Economic Development Corporation, and the Rothman of Pall Mall for special permission to use their respective premises for respirable dust particulate monitoring. Grateful thanks are also due to the Malaysian Meteorological Service for loan of radiation equipment and assistance with instrument calibration. I am also grateful to the Director of the Selangor Water Works for permission to use the grass-covered concrete dome of the Weld Reservoir for installation of meteorological equipments.

Back in New Zealand, academic and personal debts incurred during my stay are varied and difficult to pinpoint, but I would especially like to thank: Dr. D.C. Johnston, for assistance with the computer; Dr. R.G. Cant, and Dr. A.P. Sturman for reading the manuscript and much valuable guidance; Professor W.B. Johnston, for many hours of discussion and invaluable guidance at the initial draft stage; Tony Shatford, Marianne Wowk, Alistair Dyer, and David Glasson for cartographic and photographic assistance; Bob, Jean, and Tracy Wouldes for congenial company and much invaluable personal assistance during our stay in New Zealand.

A final word of appreciation must go to my wife, Siti, who proved to be not only a most capable research assistant and a good companion but also an invaluable source of encouragement throughout the project.

CHAPTER ONE

INTRODUCTION

1.1 Air Pollution: An Environmental Problem

For much of the world, the twentieth century is an urban age. Today the majority of the people in industrialized countries live in cities, and in emerging nations, industrial expansion and urban growth are seen as keys to prosperity. In recent years, however, the converging forces of population, urbanization, technology, and environment have come into serious conflict. The effects of this conflict have been especially noticeable in developed mid-latitude countries. In many areas, under certain meteorological situations, gases and small particles accumulate in such quantities that they create a pollution problem and a health hazard (e.g. McDermott, 1961 for the case of Donora, Pennsylvania in 1948; the British Ministry of Health, 1954 for the case of London fog in December 1952). Studies on the extent and effects of air pollution in tropical areas however are relatively rare. There is a conspicuous lack of data even for those aspects of environmental quality which lend themselves to measurement. Although this lack may partly reflect a scarcity of resources, it is also probably a consequence of what has been, until recently, a rather indifferent attitude toward pollution and environmental quality in general.

Air pollution has not in the past been regarded as a serious problem for Malaysia. However, with the rapid growth of urbanization and industries, and the progressive expansion of suburbs into proximity with industrial plants in certain areas, the problem of air pollution can no longer be ignored. The present report which considers air pollution and meteorology in the Kuala Lumpur - Petaling Jaya area, is a study of one aspect of the problem. It attempts to outline, estimate and assess the sources, emissions and levels of air pollution; it discusses the atmosphere's role in influencing the distribution of air pollution and assesses the possible effects of the latter upon climatic parameters. This Chapter forms a background to the study and deals with two main issues. These are: (a) to briefly review previous work in the field; and (b) to establish the context of the present study by describing the study area, stating objectives and outlining data sources and approaches to the problem.

1.2 Air Pollution Climatology

Works on urban climate in general and on urban air pollution climatology in particular have been undertaken by several workers for a number of areas. One of the earliest study of an urban climate was Luke Howard's work The Climate of London, first published in 1818, a later enlarged edition appearing in 1833. Howard's account was a remarkable pioneer study and was followed by many similar investigation in Britain (e.g. Manley, 1944; Marshall, 1952 and Chandler, 1965), continental Europe (e.g. Schmidt, 1929; Sundborg, 1950), North America (e.g. Middleton & Miller, 1936; Duckworth & Sandberg, 1954; Oke & Hannell, 1970 and Clarke, 1969) and elsewhere (e.g. Kawamura, 1964; Sekiguti, 1964 and Nieuwolt, 1966). A summary of studies of town climate was provided by Brooks (1952), Kratzer (1957), Landsberg (1956 & 1974), Peterson (1969) and more recently by Oke (1974).

Studies relating to air pollution and, in particular, its relationship with meteorological factors have also been reported extensively in the literature for a number of urban areas. A summary of related bibliography is given by Munn (1968). A review of the various ways in which meteorology enters into the description and understanding of air pollution problems has been given by Cramer (1959) and McCormick (1962). A more recent review is provided by Munn (1973a) and Munn & Phillips (1973).

1.2.1 Sources and Types of Pollutants

Community air pollution can be said to occur when any substance or group of substances is added into the atmosphere in sufficient concentration to produce a measurable effect on man or other animals, vegetation or materials (Chambers, 1962, p.12). Pollutants may therefore include almost any matter capable of being airborne. In some instances the sources of pollution are natural phenomena such as volcanoes, forest fires or dust storms. In most cases, these are however only very minor contributors to the pollution of the atmosphere when compared with discharge of pollutants as a direct or indirect result of man's activities (Figure 1).

Bach (1972a) divides man-made air pollution sources into three groups: single or point sources, multiple or area sources, and line sources. Point sources such as steel mills, power plants, and cement works with their tall stacks are usually identified as major contributors to air pollution. Equally bad because of their sheer quantity and low levels of emissions are the area sources. Residential areas, hospitals and office buildings are the greatest contributors. Line sources, such as expressways, seem to affect

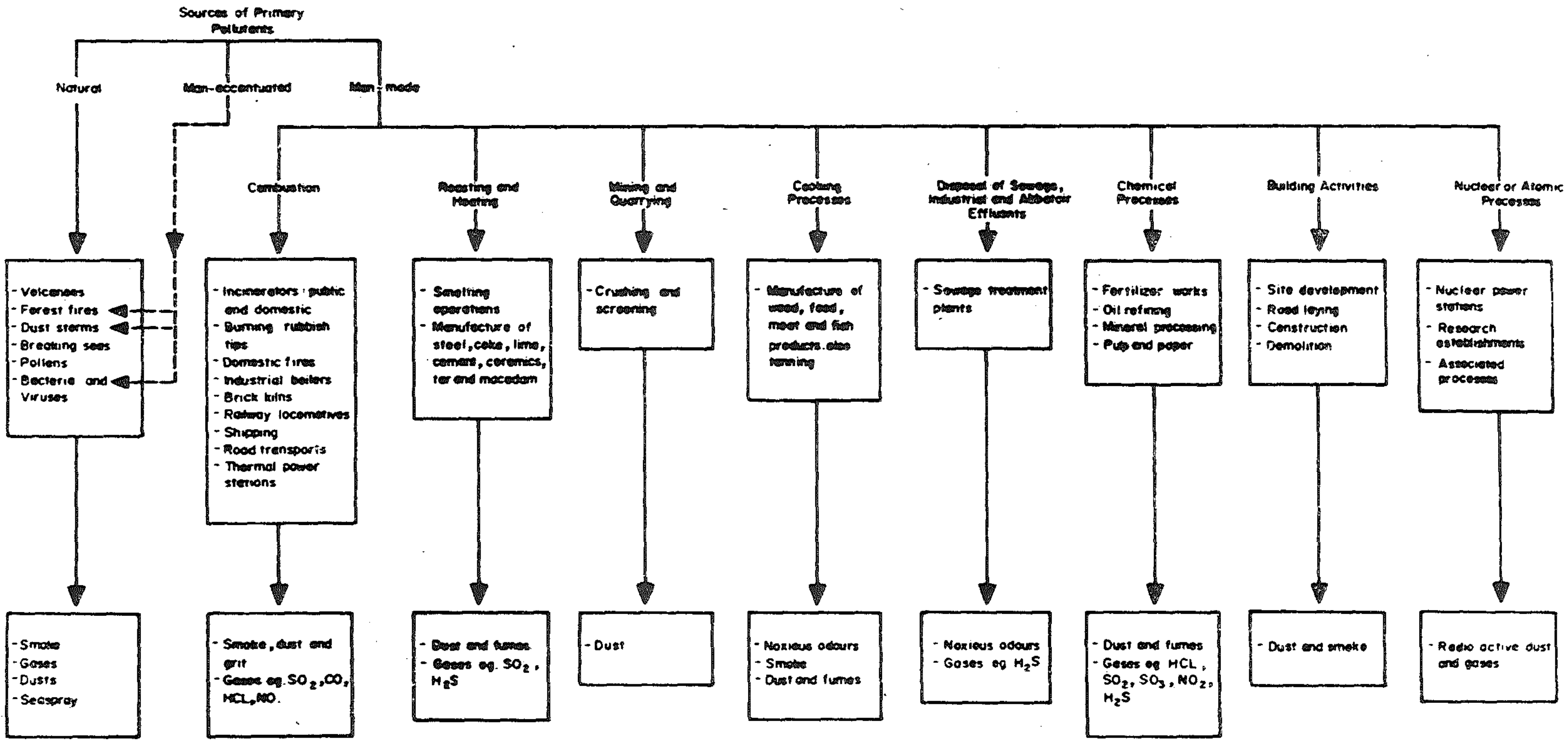


Figure 1: Some major sources of primary pollutants

only the drivers. However, in the narrow, canyon-like streets of the cities the automobiles constitute a great health hazard to the general public, because they emit not only the largest quantities of pollutants among the sources, but also because they emit the poisonous gas and particulates at breathing level. Of the major sources of air pollutant emissions in the United States, motor vehicles represent about 60 percent of the annual total (U.S. Department of Health, Education & Welfare, 1966).

Pollutants may be divided into two major categories: primary pollutants - those emitted directly from identifiable sources, and secondary pollutants - those produced in the air by interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photochemical effects.

Primary pollutants from combustion processes may be either particulate or gaseous. The particulates include ash and soot. Reduction in visibility, decreased sunlight, and soiling of buildings, plants and people are examples of effects of primary pollution by particulates. The secondary roles played by particulates are dependent on their sizes and, consequently, fall speeds. Particles larger than a few tens of microns have substantial fall speeds and do not ordinarily remain in the air long enough to play important secondary roles. Particulates smaller than about ten microns may act as nuclei for the condensation of atmospheric water vapour and freezing of atmospheric water.

Primary gaseous pollutants include carbon dioxide, water vapour and the various oxides of sulphur and nitrogen. Oxides of sulphur, chiefly sulphur dioxide, are produced by the combustion of sulphur-containing fuels (coal, fuel oils) while those of nitrogen are produced by the high-temperature combustion of coal, oil, gas, or gasoline in power plants and internal combustion engines. Carbon monoxide, as are hydrocarbon products, is a result of incomplete combustion. It is quite stable and does not directly react with other normal constituents or pollutants. It is probably slowly converted to carbon dioxide (Bryson & Kutzbach, 1968).

Secondary reactions involving these primary gaseous pollutants enable us to distinguish two general types of pollution: the 'London' type and the 'Los Angeles' type. The former consists mostly of a combination of sulphur oxides and particulates while the latter is the result of a chemical reaction between hydrocarbons, oxides of nitrogen, and sunlight. A good account of these two general types of pollution is provided by Bryson & Kutzbach (1968, p.12). Of course, there are many additional types of urban air pollution not included in the two general categories described above. Blifford & Meeker (1967) identified four principal pollution factors in the atmosphere of 30 U.S. cities on the basis of chemical composition. These are heavy industry (Fe, Mn, Ti), internal combustion engines (Pb, NO_3, benzene and soluable particulates), fuel burning (SO_4, suspended particulates), and petroleum refining (Ni, Pb). Others (e.g. Francis, 1970) have classified the various pollutants broadly into smoke, fumes, dust and odours. A detailed account of odour type pollution was provided by the Christchurch Drainage Board (1973) which summarizes the results of an investigation of odour and related matters pertinent to the Bromley Sewage Purification Works in Christchurch, New Zealand.

There are several devices and techniques for determining the concentration of pollutants in the atmosphere. However, the variety of pollutants is so large that, to date, it has only been possible to measure a small number on a regular basis. The most extensive networks of pollution recorders have been established to monitor smoke (particulates) and sulphur dioxide concentrations, but readings are often not comparable and for large areas of the world they simply do not exist. Several reviews on air pollution sampling procedures and monitoring equipments are available in Stern (1968) and Ledbetter (1972).

Besides instrumentally measured levels of pollution, attempts have also been made to develop a survey technique for estimating community air pollution emissions. One such technique has been developed by Ozolins & Smith (1968). It is based on information that is readily available in most urban areas and does not entail extensive surveys or sampling procedures. Application of this survey method will yield a series of tables and diagrams that indicate the weights of emissions of selected pollutants, and also the relative importance of various fuels and types of sources in producing the emissions. Such information constitutes a useful tool for developing an air conservation programme. In recent years such surveys have been undertaken in Auckland (Sparrow, 1969) and Christchurch (Kennedy et al, 1974) and will be repeated in the present study.

1.2.2 Meteorological Variables Influencing Air Pollution Concentration

Variations of pollution levels may be considered on at least four different time scales each of which is in some way related to climatic variables. These are: (1) long-term trends usually associated with changes in emission characteristics (e.g. Holzworth, 1962; Beebe, 1967) and often as a result of legislations (e.g. Wiggett, 1964; Freeman, 1968); (2) seasonal cycles often associated with emission especially where domestic heating is a source and normally a result of seasonal variation of temperature as in the case of Christchurch, New Zealand (Tapper, 1976) and Montreal (Summers, 1966); (3) episodic variations normally associated with particularly unfavourable weather such as those reported for London in December, 1952 (British Ministry of Health, 1954), Meuse Valley in December, 1930, and New York during January-February, 1963 (U.S. Environmental Protection Agency, 1971); and (4) diurnal variations in which both emission and meteorological variations contribute.

The meteorological parameters which have the most important influence on levels of air pollution are wind direction and speed, atmospheric stability, precipitation scavenging, and radiation and sunshine in photochemical processes. In this section, each of these variables and the way in which it influences pollution concentration will be considered in turn.

(a) Wind Direction and Speed: The wind direction and its persistence are very important factors in predicting the air pollution potential of an area when the principal sources of pollutants are high-level emitters located near each other in an industrialized-zoned portion of the city. These factors are not as important for areas in which low-level emitters cause the greater proportion of the pollution.

Since wind directs the travel of pollutants, the expected persistence of the wind direction, as related to the topographic features and the location of the receptors, must be considered both in forecasting the air pollution potential as well as in selecting sites for plants. For example, in an area which has the principal source of a pollutant on a lakeshore site, high air pollution potential conditions could be expected only when persistent on-shore winds are forecast. The deleterious influence of Lake Michigan upon the air quality of Chicago Metropolitan area in summer has been noted by Lyons (1971), while the role of wind direction in determining the contribution of Detroit-Windsor particulate emissions to the quality of the air in Sarnia-Port Huron has been discussed by Munn (undated). The effect of wind direction upon particulate air pollution in Nashville, Tennessee has been described by Dickson (1961) He found that the effect of wind direction is small when wind speeds are large but becomes increasingly dominant as wind speed decreases.

Topographical features such as valleys cause winds to persist in certain directions much more frequently than in others (Tyson, 1963). Obviously, such localities should be avoided, if possible, in selecting sites for large industries.

The effect of an increase in wind speed on the concentrations resulting from low-level sources of emissions is to dilute the pollutants - the concentration of pollutants in a downwind location from a ground-level source is inversely proportional to the wind speed. High air pollution potential forecasts for most large urban areas where low-level emissions are the principal sources of pollution include light wind speed as one of the criteria.

In contrast, with high-stack sources of hot emissions, an increase in the wind speed will lower the plume rise, and tend to increase ground-level concentrations. There is a critical wind speed for each stack design at which concentrations down-stream reach a maximum. In Ontario, Canada, Air Management Branch approval of a stack requires air quality criteria to be met at this critical wind speed, which may range between 8-48 k.p.h. (5-40 m.p.h.) depending on the stack design (Shenfeld, 1970a; Nelson & Shenfeld, 1965) and the height of and distance to the receptor.

(b) Atmospheric Stability: The rate of change of atmospheric temperature with increasing altitude is of critical importance to the ease with which pollutants can be diluted by vertical mixing with cleaner air. Figure 2 depicts three basic patterns and three transitional patterns of plume which are frequently mentioned together with the lapse rate conditions producing them. The basic patterns are looping, coning, and fanning which occur, respectively when the temperature decreases rapidly with height (unstable lapse conditions), decreases only slowly with height or is constant (near-neutral conditions) and increases with height (stable inversion conditions). The transitional patterns are lofting, fumigation, and trapping. Lofting occurs when the stack extends through a surface inversion to an unstable layer above. Fumigation and trapping occur when an unstable or near-neutral surface layer is capped above the stack by an inversion.

Bierly & Hewson (1962) distinguish between three types of fumigation. The first and most common type is associated with the burning off of a surface inversion shortly after sunrise. Solar heating of the ground causes a shallow, unstable layer that grows in depth as the day progresses. When the top of the layer reaches stack height, the effluent is brought to the ground suddenly in high concentrations. Fortunately this condition usually persists for less than an hour. The second type of fumigation occurs on clear, nearly calm, evenings when radiationally cooled and stable air from a rural area moves over an urban area, which acts as an artificial heat source long into the night. The third type of fumigation is associated, for example, with airflow from cool water to warm land during the day in the spring and summer and from cool land to warm water during the night in the autumn and winter. Here

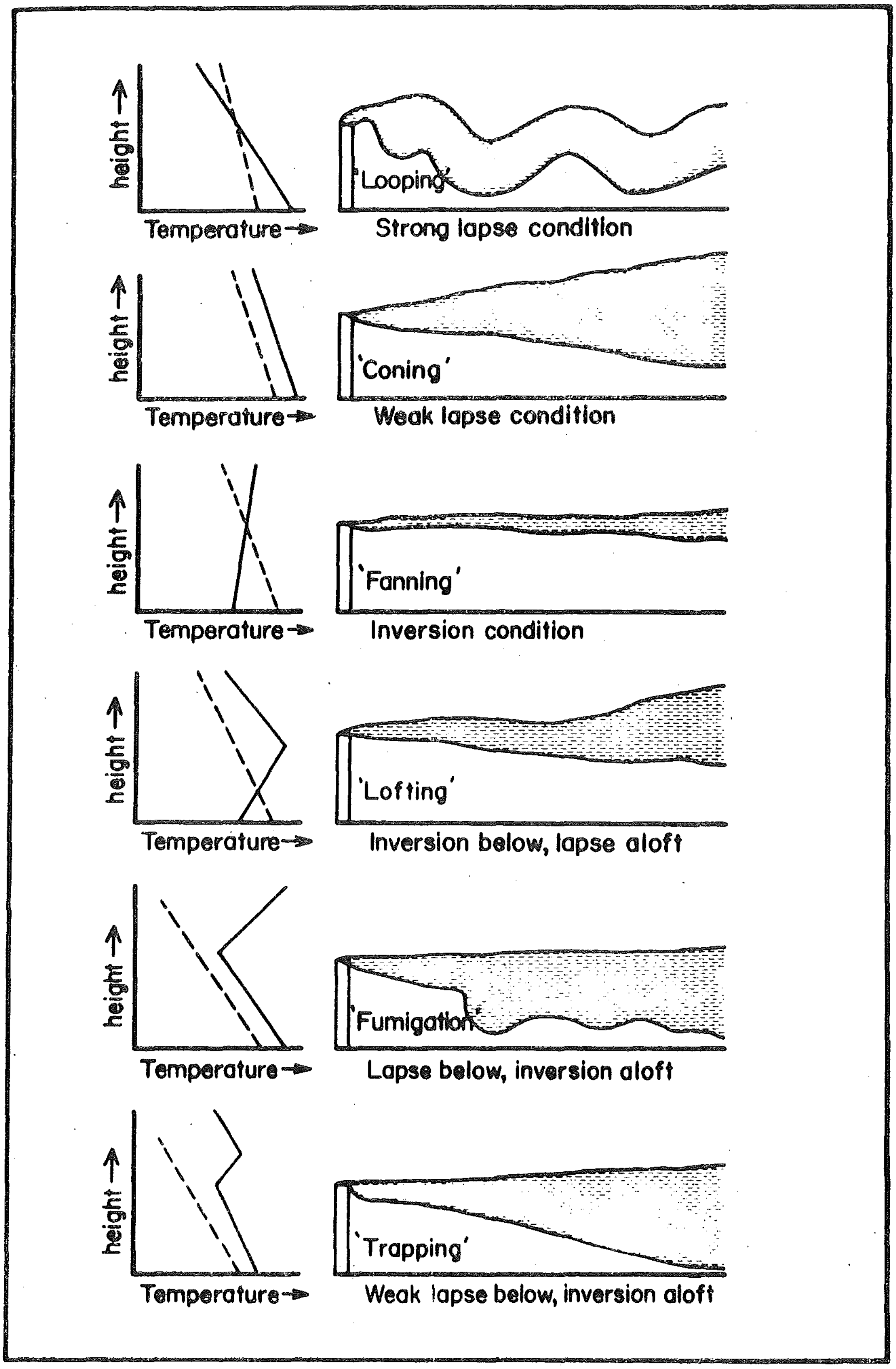


Figure 2: Six types of plume behaviour under various conditions of stability and instability. The broken lines at left are dry adiabatic lapse rates. The solid lines are existing lapse rates (adapted from Bierly & Hewson, 1962 as quoted by Sellers, 1965 and Lowry, 1970)

the heat source is a natural one.

The last diffusion pattern, plume trapping, occurs when an upper-level inversion physically traps the effluent from a stack in the surface air layers. In a sense, this is similar to fumigation. However, trapping is associated mainly with subsidence inversion, which may persist for months, and to a lesser extent with frontal inversions, which usually last less than a day. Because it can be so persistent, plume trapping is the most dangerous and deadly of all the diffusion patterns and was responsible for the disastrous episodes which occurred in the Meuse Valley in Belgium in 1930; in Donora, Pennsylvania, 1948; and in London, England in 1952 (Goldsmith, 1962). Each location is within a heavily industrialized valley and in each case light winds, fog, and temperature inversion persisted for at least five days. This situation permitted contaminants to accumulate to unprecedented levels.

(c) Precipitation Scavenging: An aerosol can be scavenged from the atmosphere by rain through two basic processes (Shaw & Munn, 1971). The first is termed in-cloud scavenging by the cloud elements and precipitation, usually called rainout and snowout. It is the result of the aerosol serving as a cloud nucleus or undergoing capture by cloud water or ice particles. The second process is termed below-cloud scavenging, usually called washout. It is due to the removal of the sub-cloud aerosol by the raindrops as they fall.

The relative importance of these processes in atmospheric cleansing is difficult to assess. Each depends on the nature of the aerosol, its size distribution, concentration, wettability, and activity as nuclei. For rainout process, it also depends on the nature of the cloud itself; its depth, temperature and water distributions, electrical activity and other parameters. The washout process depends on the characteristics of the rain, including the raindrop size distribution, and the amount of aerosol collected by the individual raindrops. For rain, the best known size distribution is that given by Marshall & Palmer (1948). The size distribution of snowflakes is not as well known as that for rain. Snow can take many crystalline forms (Nakaya, 1954), each of which has its own cross sectional area and fall speed characteristics. The collection efficiency of raindrops is discussed by Mason (1957), McDonald (1963), and Berg (1963). Very small (less than 1.0μm diameter) pollutant particles tend to move out of the way of the scavenger; however, electrical attraction offsets this effect (Byutner & Gesina, 1963; Fuquay, 1970). Relatively little is known about the collection efficiency of snow. Slowly falling snowflakes should be efficient collectors of small particles (Georgii & Weber, 1964; Perkins & Engelmann, 1966) but Facy (1962) suggests that they may in fact shed particles.

(d) Radiation and Photochemical Smog: Photochemical smog is the result of a chemical reaction between hydrocarbons, oxides of nitrogen, and sunlight. The primary pollutants involved in photochemical smog are nitric oxide (NO) and hydrocarbons. When these primary pollutants are together in the presence of sunlight, a partially understood complex series of reactions takes place which results in various harmful secondary pollutants, including nitrogen dioxide (NO_2), Ozone (O_3), and peroxyacetyl nitrate (PAN, $CH_3CO_3NO_2$). Ozone and PAN are usually referred to as photochemical oxidants.

1.2.3 Urban and Regional Pollution Models

In recent years a number of models have been developed to predict the dispersion of contaminants in urban atmosphere. These models range in complexity from those designed to solve the three-dimensional diffusion equations (e.g. Randerson, 1968 & 1970) to models containing only one parameter (e.g. Halliday & Ventner, 1971; Gifford & Hanna, 1973). The performance of simple, one parameter, models for predicting dispersion of air pollutants in urban atmospheres as compared with that of more complex methods has been discussed at length in a series of articles by Hameed (1974 & 1975), Benarie (1975), and Gifford & Hanna (1975).

Two general approaches are apparent in air pollution modelling. The source-oriented approach is to make an inventory of all emissions (commercial and residential), to undertake a separate diffusion calculation for each source, and to superimpose the resulting pollution patterns upon each other (Moses, 1969). Emissions from large factories and generating plants are considered as point sources, while residential heating units are grouped together as area sources, while residential heating units are grouped together as area sources. Alternatively, a receptor-oriented approach may be taken (e.g. Clarke, 1964). An estimate is made of the pollution arriving at each of many fixed grid points from sources located in angular upwind segments centred on the receptor. Johnson _et al_ (1969) have modelled the urban distribution of carbon dioxide, 98 percent of which is emitted by motor vehicles, in this way.

One of four patterns of dispersion is assumed: box, plume, puff, or gradient-k. The box model has been discussed in the literature by Lettau (1970), Reiquam (1970a & b) and Hanna (1971), while an account of the Gaussian Plume is provided by Bach (1971c). Roberts _et al_ (1970) claimed that his 'integrated puff' model provides a more realistic physical simulation of the processes of smoke plume dispersion than has hitherto been employed. Unlike previous models, it provides for simulation of near-zero wind speed conditions, models three-dimensional wind vector variation and atmospheric diffusion, and permits variations of stability and mixing layer depth with time. Randerson (1970) illustrated the use of a k-theory to predict the dispersion of sulphur dioxide over Nashville, Tennessee. An evaluation of the performance of this model is discussed by Gifford & Hanna (1975) and Hameed (1974).

Numerical models offer exciting possibilities for future air management programmes. As early as 1956, Frenkiel (1956) realized the potential usefulness of this regional approach but only recently has there been a serious attempt to develop his ideas. The present position is that advances in digital computing are well ahead of those in our knowledge of mesometeorological flow patterns and of atmospheric pollution residence times (Shaw & Munn, 1971). In addition, there is difficulty in obtaining sufficiently accurate source inventories. The diurnal cycle in emission strengths is not well documented in many areas, for example. Hilst (1969) has undertaken a useful sensitivity analysis of the Connecticut regional SO_2 model, in which the values of the variables were deliberately changed to determine which elements were of most importance. His studies indicated that predictions were relatively insensitive to the values of the cross-wind diffusion rate, and to random errors in source strengths; the forecasts were, however, strongly dependent on wind directions. This kind of study is to be encouraged, as an aid in designing urban and regional mesometeorological network of stations.

There are two other types of models for pollution predictions. The first of these is the area diffusion model which is based on concepts developed by Miller & Holzworth (1967). Specifically, the model calculates normalized pollutant concentrations as a function of mixing depth, wind speed through the mixing layer, and size of the area. The resulting estimates are given in terms of meteorological potential for air pollution. This simply means that for given emission rates the meteorological conditions determine uniquely the pollutant levels. This type of information is valuable in the appraisal of an area's potential air quality, and it could play an important role in an area's urban and industrial planning policy.

The second model is empirical in approach and aims to establish the role of meteorological factors in pollution concentration. Multivariate analysis and contingency tables are frequently used to relate air quality to several meteorological factors. However, the data do not often meet the significance-test requirements for random unbiased statistical samples. For instance, a regression between pollution concentrations and wind speed is biased because the lighter winds are more likely to occur at night (Munn, 1970a). Prestratification of samples according to season and time of day is a help but does not eliminate interactions completely.

1.2.4 The Influence of Pollution on Climatic Parameters

There is a two-way relationship between meteorological processes and atmospheric pollution. The effects of weather and climate upon the concentrations of atmospheric pollutants have been presented. It is now necessary to turn to the complementary problem of the implications of air pollution for atmospheric processes for there is considerable evidence to suggest that air pollutants actually bring about modifications in weather and climate.

A number of summaries of research on urban climates have been published and these indicate that there is hardly any element of the weather that is not influenced, directly or indirectly, by air pollution (Landsberg, 1956 & 1974; Chandler, 1965; W.M.O, 1970; Peterson, 1969; Oke, 1974). However, the release of pollutants is not the only contributing factor. The artificial generation of heat, the high conductivities, heat capacities and albedoes of the built environment, and alterations in relative humidity through modifications of the hydrological cycle, are among the many elements and generators of change. In consequence, it is extremely difficult to isolate the independent effects of pollution. The general influence of air pollution and urbanization upon climatic parameters is therefore reviewed together in this section.

Most of the obvious atmospheric effects of urban pollutants are caused by the particulates. They deplete the solar and sky radiation in all wavelengths. The average reduction in urban areas are observed to be between 8.0 and 30.0 percent depending on size of the city, topographic setting, and ventilation rate (Landsberg, 1970). The light-attenuating properties of the aerosol have also a notable impact on the horizontal visibility. Many investigations, especially for earlier years, have shown a deterioration of visual ranges in the city compared with rural areas. For a while this led to an increase of cases with very low visibilities and a large reduction in the cases of long distance visibilities. In recent years however the same reversal of the trend already noted for sunshine has also been observed for very low visibilities (Brazell, 1964; Freeman, 1968).

Urban effects upon precipitation have been noted for a number of decades but were relatively hard to verify by statistical test. The reason for this is the very high variability of rain amounts and the poor qualities of the ordinary rain-gauge as a sampling device. Landsberg (1956) gave several European examples of urban-rural comparisons and concluded that the amount of precipitation over a city is about 10 percent greater than nearby country areas. More recent studies have shown that the greatest positive anomalies occur downwind of the city centre. One very striking example of the effect of the Chicago urban region on local precipitation at La Porte has been documented by Changnon (1968). Changnon (1961, 1962, 1968, & 1969) has summarized precipitation data for several other mid-western cities and detected positive increases, but not nearly as pronounced as those at La Porte. Authors do not totally agree however on the distribution of precipitation over cities. Some workers (e.g. Holzman & Thom, 1970; Ogden, 1969 & 1971) have challenged the results obtained by Changnon (1968) and suggested that there might have been some kind of observational bias.

Of all the urban-rural meteorological differences, those of air temperatures are probably the most documented. That the centre of a city is warmer than its environs, forming a 'heat island' has been known for more than a century and continues to receive considerable attention in the literature. Summaries of research on the subject have been provided by Landsberg (1956) and more recently by Tyson et al (1973) and Oke (1974). Oke (1974, p.45) noted that probably the single most important development in the study of heat islands since the Brussels Symposium on Urban Climates and Building Climatology in 1968 has been the increase in our knowledge of the vertical temperature structure. Much remains to be done, but it is clear that the thermal influence of a large city commonly extends up to 200-300m and even to 500m (e.g. Bornstein, 1968; Clarke, 1969; Tyson et al, 1972).

There has been little research done on humidity distribution in cities. However, the consensus of urban climatologists is that the average relative humidity in towns is several percent lower than that of nearby rural areas where as the average absolute humidity is generally slightly lower in built-up regions (e.g. Goldreich, 1969; Preston-Whyte, 1971) although a moisture deficit as great as 2.5g kg^{-1} has been reported over downtown areas (Dirks, 1974). The humidity differences are found greatest at night and in summer, corresponding to the time of greatest heat island intensity (Chandler, 1967a & b).

The flow of wind over an urban area differs in several aspects from that over the surrounding countryside. Munn (1970) and Landsberg (1972) provide reviews of urban airflow and distinguish between conditions with strong and weak regional flow characteristics. In the former case the city tends to modify the flow, in the latter it may generate its own circulation system. Observational evidence to support the existence of this type of simple direct circulation has been given by Pooler (1963) for Louisville, Findlay & Hirt (1969) for Toronto, Georgii (1970) for Frankfurt, Schmidt (1963) and Schmidt & De Boer (1963) around a localized industrial heat source within an urban area in a Dutch City, Davidson (1967) in New York, Okita (1960 & 1965) for Ashikawa, Japan, and by Chandler (1960 & 1961) for London and Leicester. Ryan's study in Christchurch, New Zealand (Ryan, 1977) shows that over sloping ground, katabatic, or surface drainage winds may occur and are significant in air pollution dispersion studies. The general effect of topography with regard to valleys and hollows upon airflow pattern has been provided by Tyson (1963). Thus, while air pollution concentration appears to depend on weather factors, air pollution (along with urbanization) can also change weather and climate considerably on a local and regional scale.

1.3 The Present Study

The brief review of urban climatology and air pollution studies presented in the previous section indicates that while much research is being done in high and mid-latitude cities very little is known of the characteristics of and factors influencing pollution in the low latitude areas. Chandler (1970, p.viii) notes that 'models in one climate need not necessarily work in another' and emphasizes 'a need to improve our somewhat limited knowledge of urban climates in low latitudes'. The present study, therefore, represents a contribution to an understanding of air pollution climatology in low latitude areas in general and in Malaysia, a developing nation, in particular where urbanization and industrialization have become one of the objectives of the First, Second and Third Malaysia Plan.

The scale of the present study is at the level of a large urban area, Kuala Lumpur - Petaling Jaya. It is felt that because of the exploratory nature of the study, an area such as this is a good starting point for more detailed investigations in the future.

1.3.1 The Kuala Lumpur - Petaling Jaya Area

Kuala Lumpur - Petaling Jaya (lat. 3° 08'N; long. 101° 44'E) (Plate 1) is located in the Kelang Valley, Peninsular Malaysia. It covers approximately 261 square kilometers (102 square miles) and includes some 750,000 people in 1970 (Chander, 1973). The

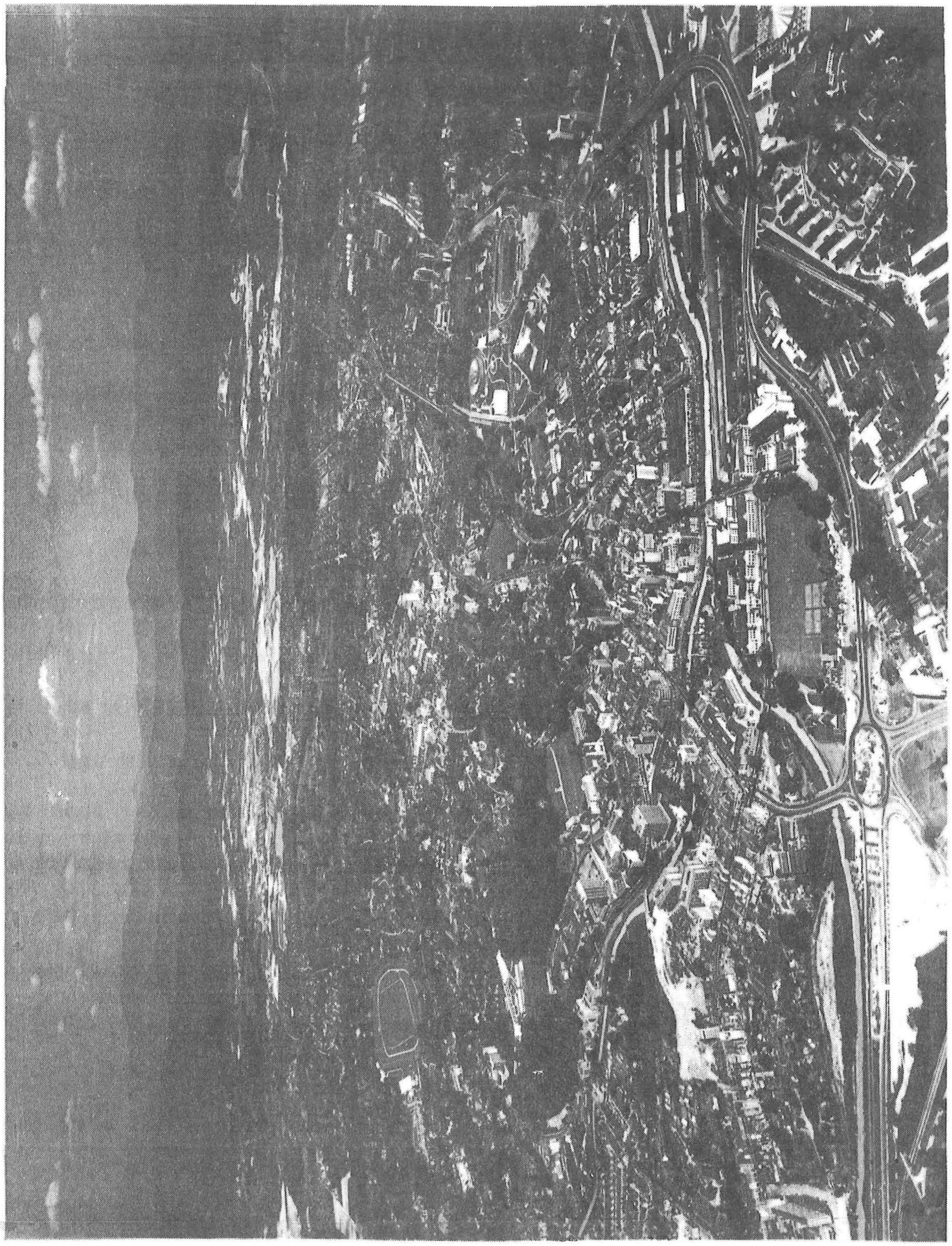


Plate 1: Parts of Kuala Lumpur - Petaling Jaya from the air

topography of the area is illustrated in Figure 3.

Kuala Lumpur is the most important urban centre in the Kelang Valley (Figure 4). In 1970, metropolitan Kuala Lumpur contained 43 percent of the population of the State of Selangor, and 8 percent of the population of Peninsular Malaysia (Pryor, 1973). The importance of Kuala Lumpur will probably be accentuated in the near future now that the 92-square kilometer (36-square mile) municipal area of the City has been extended into a new 241-square kilometer (94-square mile) Federal Territory of Kuala Lumpur. The general landuse patterns of Kuala Lumpur and the location of the central city in relation to the surrounding area are shown in Figure 5.

Less than 10 km (6.0 miles) away to the soutwest of Kuala Lumpur is Petaling Jaya, Malaysia's first new town. In 1975 Petaling Jaya covered approximately 20 square kilometers (8 square miles) with slightly under 2.6 square kilometers (1.0 sq. mile) devoted to some 300 factories. It is now one of the most industrialized towns in the Peninsular (McTaggart, 1972). At present the development of Petaling Jaya is almost complete. It can no longer accommodate the growing demands for urban houses close to Kuala Lumpur, and another new town, Sg. Way - Subang is already taking shape to the west (Figure 4).

Section 51 was the first of the industrial areas to be developed in Petaling Jaya (Figure 6). Response was slow when applications for sites were first called for. However, after Independence in 1957, and the passing of the Pioneer Industries Act in 1958, the development became more rapid. The demand for sites became so pressing that eventually a second area had to be opened up to the north of the Federal Highway in Section 13.

The growth of Kuala Lumpur - Petaling Jaya in the Kelang

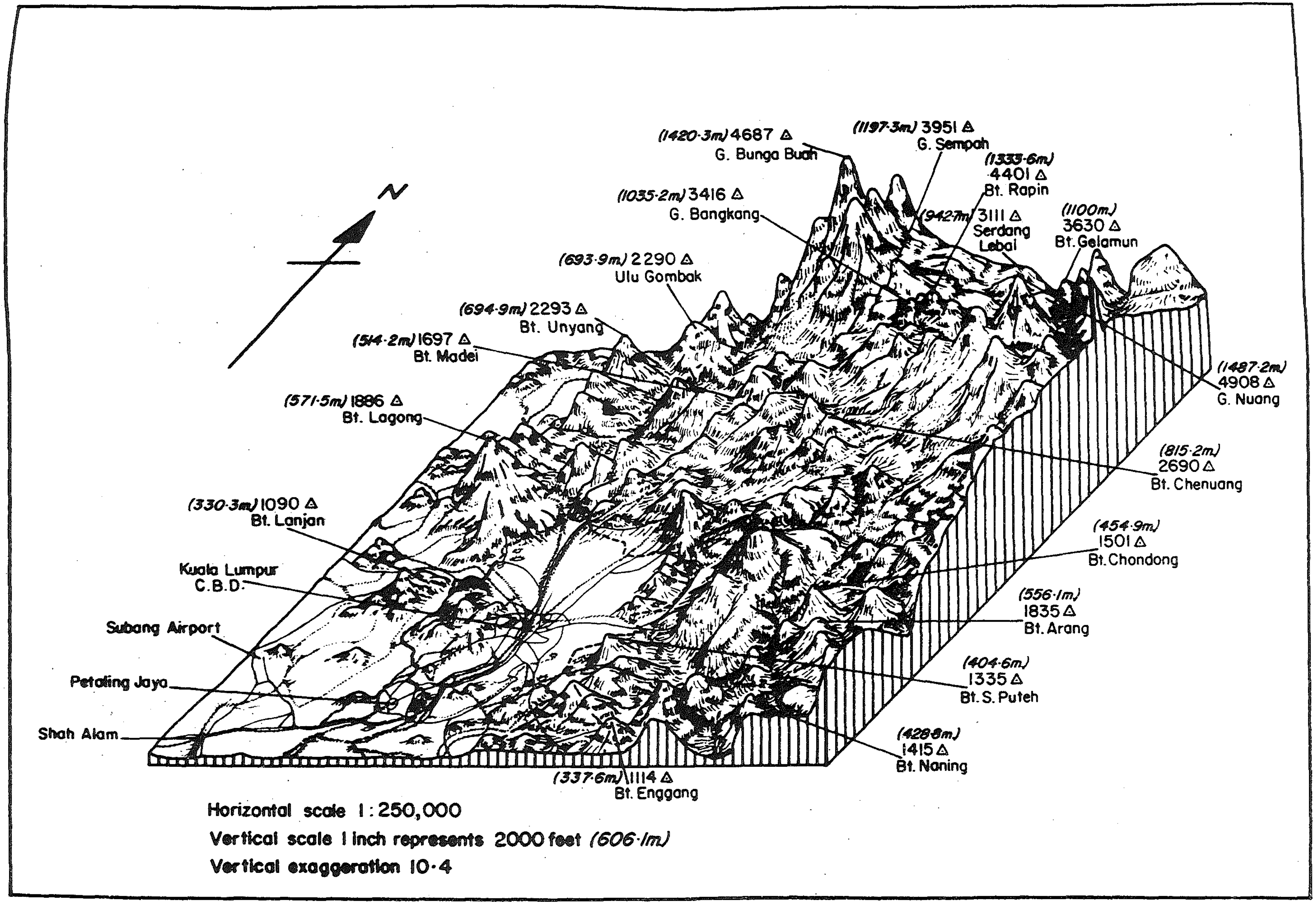


Figure 3: Kuala Lumpur - Petaling Jaya and its environs. Heights are given in feet with their equivalents in metres shown in brackets

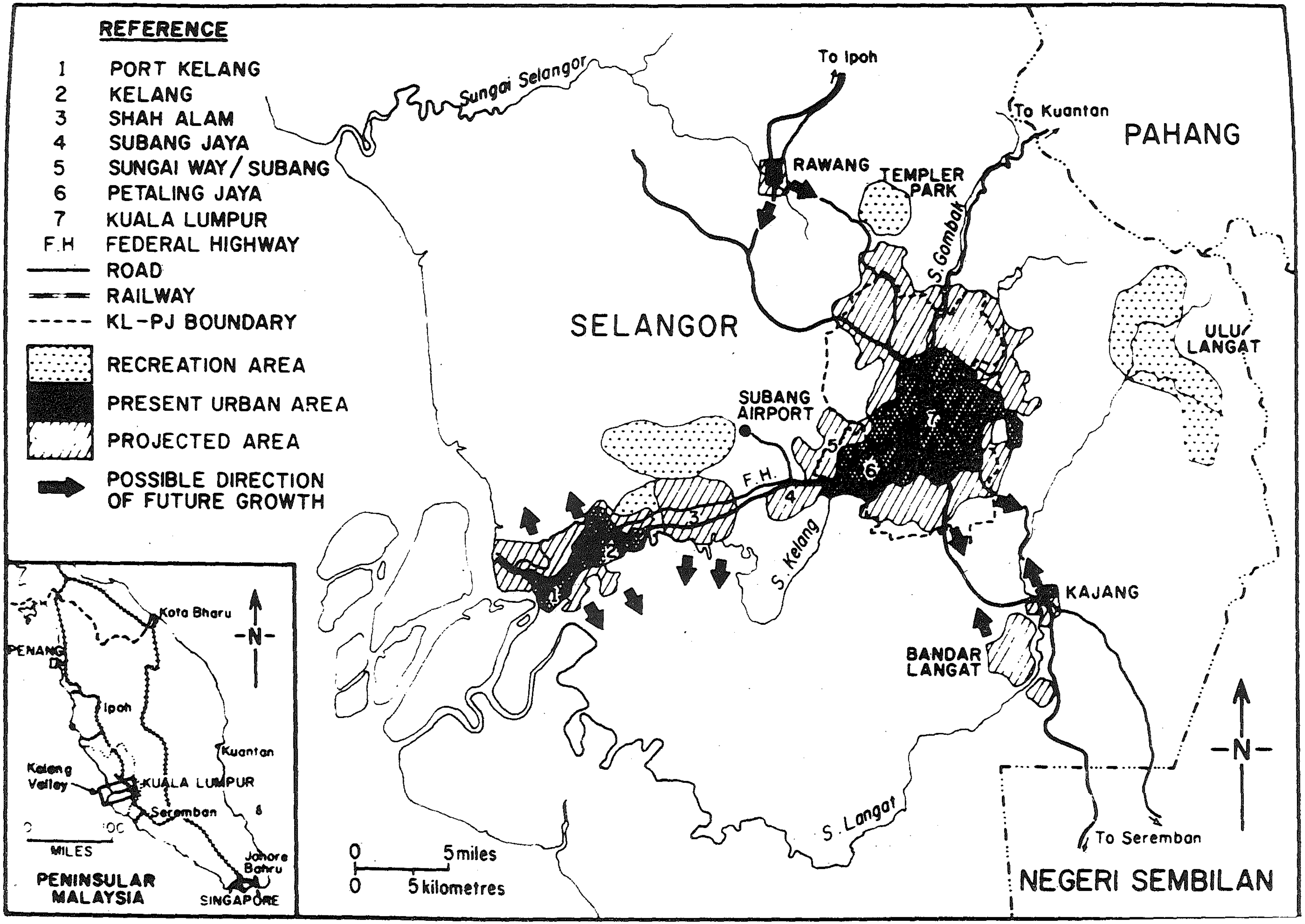


Figure 4: Kuala Lumpur - Petaling Jaya and its relation to other urban centres within the Kelang Valley (after Aiken & Leigh, 1975)

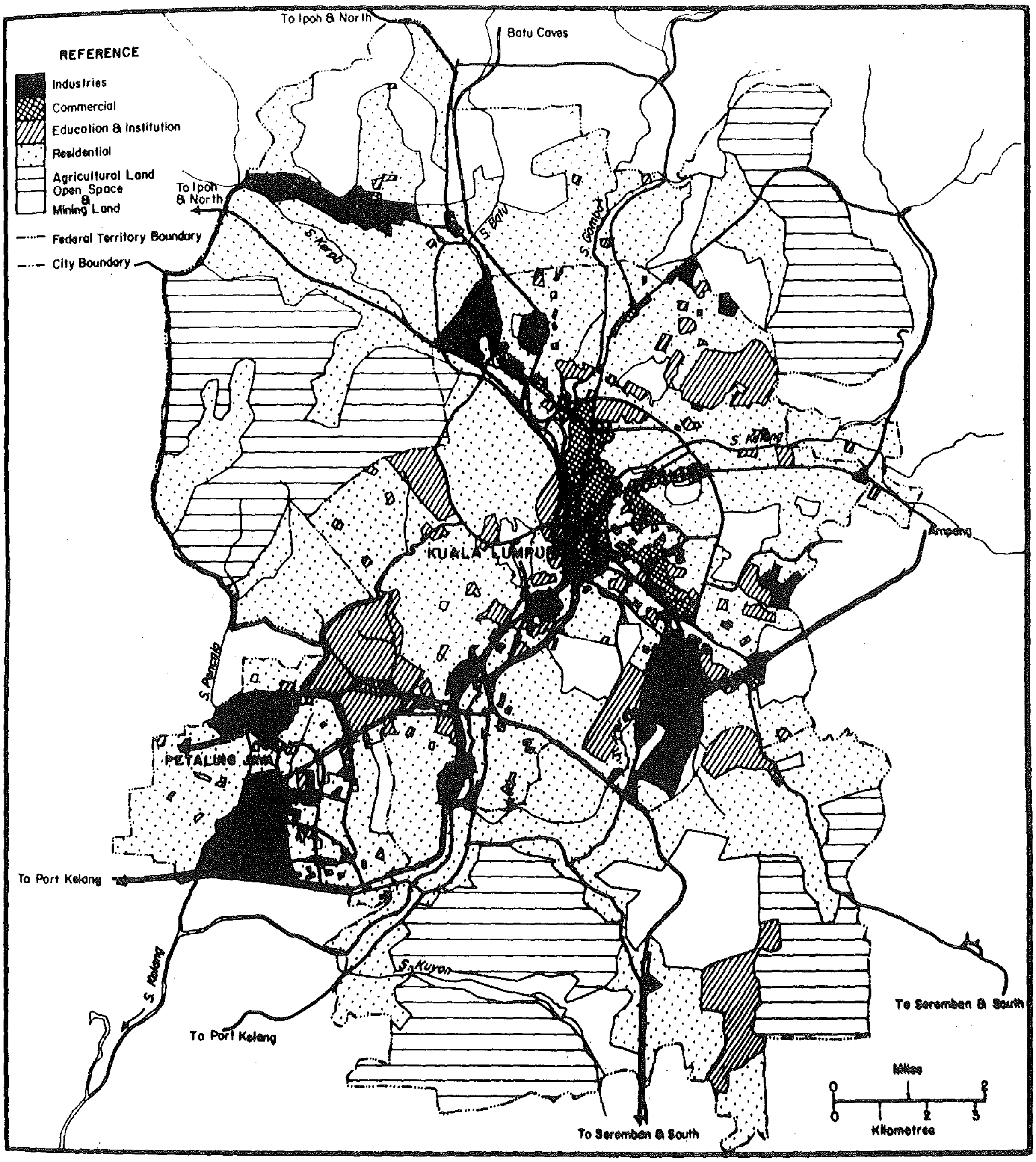


Figure 5: The general landuse patterns of Kuala Lumpur - Petaling Jaya

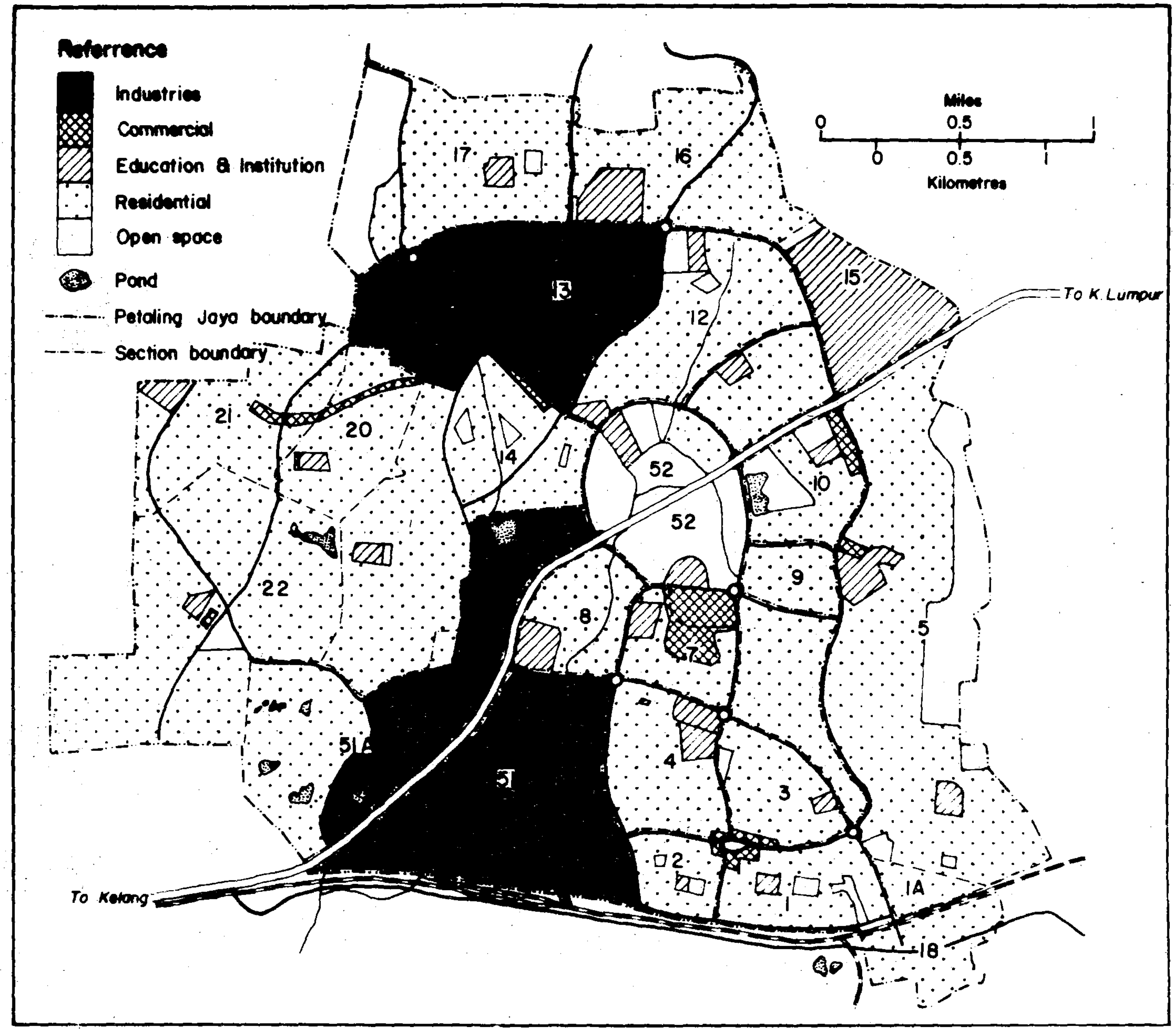


Figure 6: Petaling Jaya : land use

Valley has generated a number of problems. Some are common to cities the world over, but others are more typical of cities in tropical or developing countries, or reflecting specifically the local physical setting. One of these problems which is directly relevant to the present study is vehicular congestion.

Traffic congestion in Kuala Lumpur - Petaling Jaya in particular and in the Kelang Valley in general is a product of the rapid increase in the number of road vehicles. Congestion is most pronounced in the older areas of Kuala Lumpur, which have narrow streets and inadequate parking facilities. The expansion of Petaling Jaya and Sg. Way - Subang has been accompanied by a marked growth in the number of people commuting to and from Kuala Lumpur. Commuters are forced to depend on road transport, and traffic densities have increased, particularly along the Federal Highway, the major route linking Kuala Lumpur and the urban areas west of the City. In eastern Petaling Jaya, 8.0 km (5.0 miles) from the centre of Kuala Lumpur, the average daily flow of vehicles along the Federal Highway increased from approximately 67,000 in 1969 to 80,000 in 1972, and to more than 90,000 in early 1974 (Aiken & Leigh, 1975). This route will probably become more congested with the development of Subang Jaya and Shah Alam, and the continued expansion of Kelang and Port Kelang (Figure 4).

The development of industrial activities in Kuala Lumpur - Petaling Jaya for the last 10 years represents another area of concern which is directly related to the present study. Although by western standards the factories are largely small-scale, in terms of proportion of energy use, industrial activities form an important source of air pollution.

From this point of view therefore, Kuala Lumpur - Petaling Jaya appears to be a good location for a study of air pollution in a tropical city because it represents a large urban area where potentially polluting activities have reached significant levels and are continuing to grow rapidly.

1.3.2 Data Sources

There are several sources of information upon which the present study is based. Generally these fall into three major groups: the manuscript data, data obtained from fieldwork and those from unpublished reports and interviews (Figure 7). Climate and air pollution stations used in the study are shown in Figure 8.

A reasonable amount of climate data were available from several sources although the length of the records was limited. Information on air pollution was largely restricted to some previous studies; actual measurements during the field-study period (July, 1975 - June, 1976) were confined only to those of respirable dust particulates. Because of the exploratory nature of the study and the lack of actual measurements particularly with respect to air pollution, considerable reliance had to be made upon results from emission survey which was largely based on information of total fuels supplied to the study area by the oil and gas companies.

A more detailed treatment regarding procedures and data and their limitations will be given as they arise later in the report.

1.3.3 Aims and Thesis Format

In the context of previous findings in the air pollution climatology literature and within the constraints of data availability mentioned above, the following aims were established:-

(1) to describe the general climate of Kuala Lumpur - Petaling Jaya and its likely implications on air pollution.

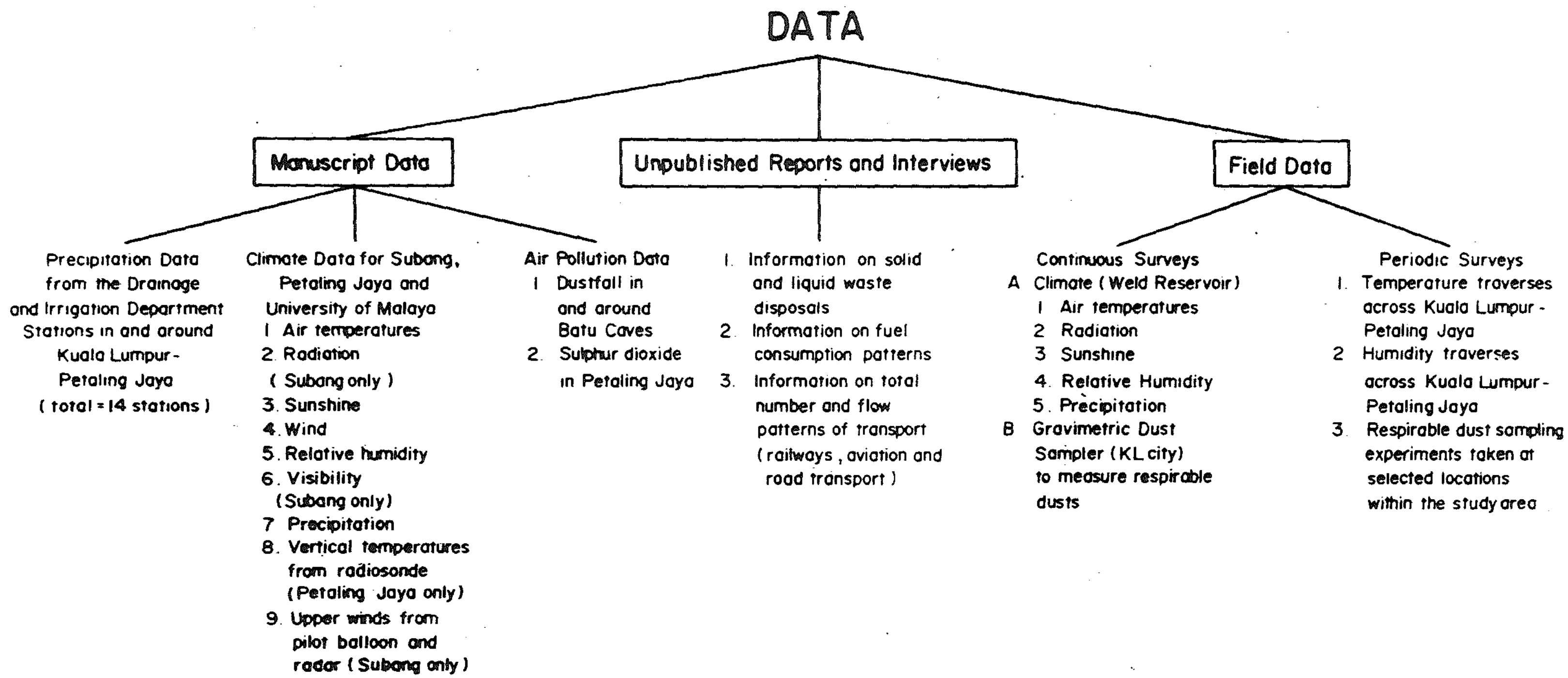


Figure 7: A summary of types of data and information sources used in the present study

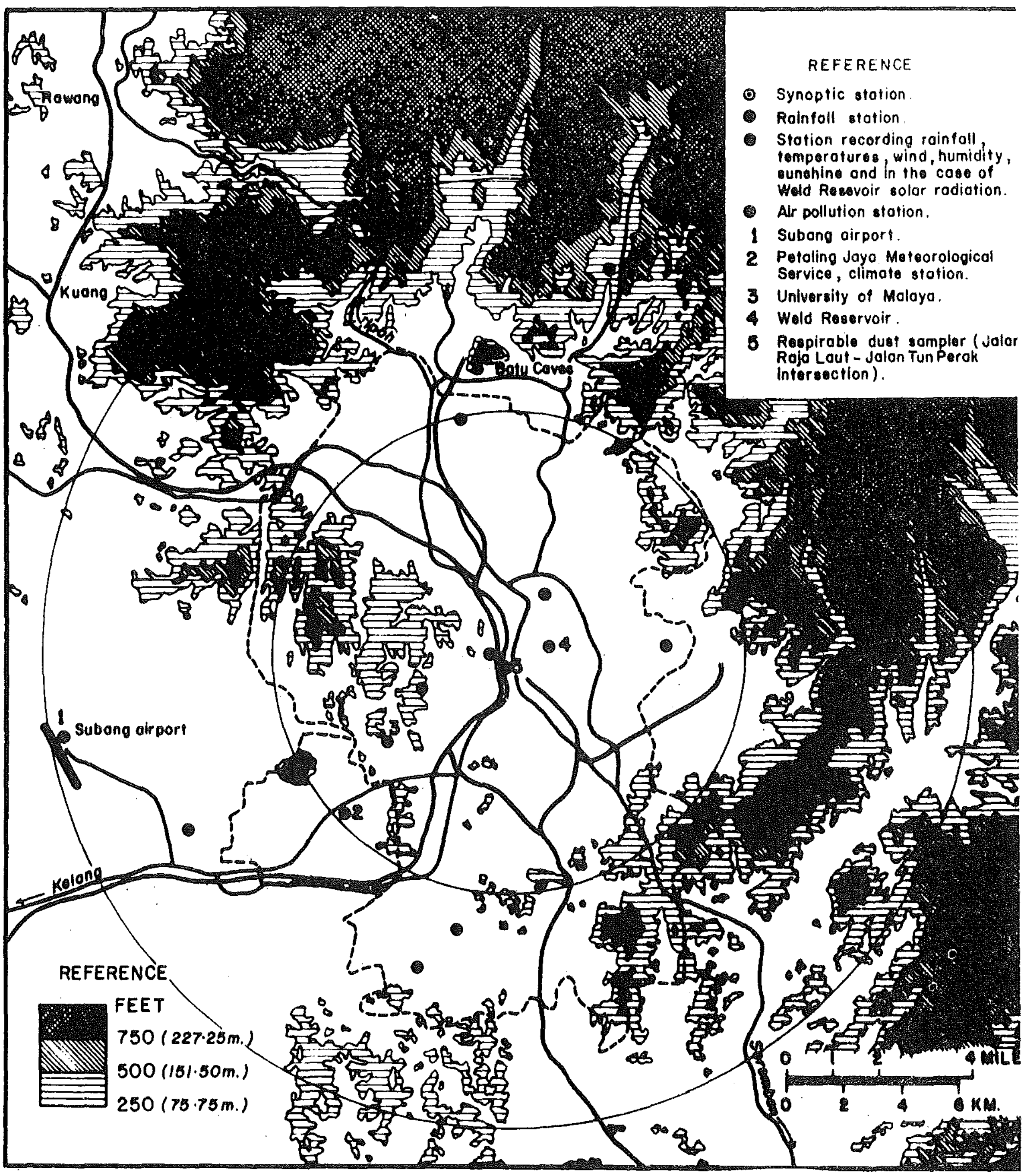


Figure 8: Kuala Lumpur - Petaling Jaya showing climate stations and air pollution station used in the study

(2) to examine the rate and nature of emissions occuring in the study area.

(3) to attempt to establish the general level of concentration of selected pollutants.

(4) to investigate the influence of local weather factors on pollution concentration and dispersion, and to see whether or not periods of high atmospheric pollution might be anticipated on the basis of weather factors.

(5) to examine the possible impact of air pollution along with urbanization on climatic parameters within the Kuala Lumpur - Petaling Jaya area.

The research strategy adopted is outlined in Table 1 which indicates the tasks and variables associated with each aim. Aim (1) is dealt with in Chapter 2 which consists of a general description of the local climate of Kuala Lumpur - Petaling Jaya and its likely implications on air pollution. In Chapter 3 both published information and the results of field surveys are brought together to establish an emission inventory for the Kuala Lumpur - Petaling Jaya area. Actual pollution levels for selected pollutants and climatic variables affecting them are considered in Chapter 4. In Chapter 5 the effects of air pollution and urbanization on climatic parameters are considered by comparing measurements from Kuala Lumpur - Petaling Jaya with those from nearby rural areas. The conclusion, Chapter 6, assesses the broader implications of the investigation and suggests areas of further research.

TABLE 1

Research Strategy

	Task	Aim	Variable
A	Outline the character of Kuala Lumpur - Petaling Jaya climate and discuss its likely implications on air pollution.	1	Wind, radiation and sunshine, air temperatures, humidity, visibility, cloud amount, and precipitation.
B	Calculate rate of emission of gases and particulates.	2	Fuel consumption, number of motor vehicles, aircraft movements, industries, mining activities, and refuse and sewage disposals.
C	Measure actual concentration of atmospheric pollution.	3	Sulphur dioxide (SO_2), dustfall, and respirable dust particulates.
D	Investigate variation of climatic variables likely to affect air pollution concentration and dispersion.		Mixing depth variations; wind speed and direction; rain scavenging effects.
E	Compare information obtained in (C) and (D).	4	As in (C) and (D).
F	Using areas 'unaffected' by urbanization and pollution as control areas, investigate variation of climatic variables in urban and pollution-affected areas. Examine if climatic variables in these areas differ significantly from those in the control areas.	5	Wind, radiation and sunshine, air temperatures, humidity, visibility, and precipitation.

CHAPTER TWO

THE REGIONAL CLIMATE OF KUALA LUMPUR - PETALING JAYA

2.1 Introduction

The main aims of this Chapter are two-fold. The first is to attempt to establish the degree to which Kuala Lumpur - Petaling Jaya has a 'typical' tropical climate; and second, to assess the implications of this climate for air pollution potential. The discussion will be at the scale of regional macroclimate as described in Barry (1970) and deals with the major elements of climate.

2.2 Data and Their Limitations

As the main concern of the present Chapter is only with the general climate of Kuala Lumpur - Petaling Jaya and its subsequent implications on air pollution, data from Subang Airport (30.6m or 101 feet a.m.s.l.) which is located away from the built-up area have been used. Records of observation of major climatic elements at Subang Airport have been maintained by the Malaysian Meteorological Service and most of these are now available from 1966. Solar radiation as measured by the Casella bimetallic actinograph has been recorded only relatively recently, however, and data are available from 1973.

Radiosonde date for the Kuala Lumpur - Petaling Jaya area are available only for the Meteorological Service Headquarters in Petaling Jaya and are obtainable twice daily: at 0730 and 1930 hours (L.S.T.). These are now available from 1972 and 1973 respectively, and have been used in the calculation of mixing depths and estimating atmospheric stability in the Kuala Lumpur - Petaling Jaya area.

The brevity of records which was noted earlier in Chapter 1 posed a major problem. The shortness of record has made it difficult to make any form of generalization with much confidence. However, in the absence of a better set of data, it is felt that when used with caution the data can be useful in understanding the general aspects of Kuala Lumpur - Petaling Jaya climate.

2.3 The Synoptic Weather of Peninsular Malaysia

Peninsular Malaysia is dominated by nine major air streams which enter the equatorial portion of Southeast Asia from both hemispheres. These are summarized in Table 2. A further source of less importance is Borneo, where small, shallow anticyclones may become stationary long enough to be separate entities (Watts, 1949). In general, air may flow into Southeast Asia from any direction other than the north, and each direction is normally linked to seasonal changes. Currents from the north rarely enter the region because, although an extensive source exists in the Siberian High of the northern winter, the mountainous country of the Himalayas, of Burma and northern Thailand hinders a direct outflow of this air southward. Fuller accounts regarding air streams affecting Peninsular Malaysia and Southeast Asia in general have been given by Fletcher (1945), Grimes (1937), and John (1949) and are summarized in Watts (1955) and Ramage (1971).

Dale (1956 & 1959), based on the direction and speeds of the air streams that cross the Peninsular, recognizes four seasons

TABLE 2

The Classification of Airstreams Affecting Peninsular Malaysia and Equatorial Southeast Asia Based on Their Trajectories (after John, 1949)

Latitude	Nature	Symbol	Source and modification	Remarks
Polar	Continental	Ps	Northeast and Central Siberia	Reaches Peninsular Malaysia only after modification
		NPs (land)	Modified over China and Indo-China	Seldom reaches Peninsular Malaysia without further modification over the sea
		NPs (cold sea)	Modified over Sea of Japan, Yellow Sea, South China Sea	Reaches Peninsular Malaysia as a burst of the northeast monsoon in late December and in January
		NPs (warm sea)	Modified over West Pacific and South China Sea	Reaches Peninsular Malaysia with properties similar to T_{NP} as a component of the Northeast Monsoon
Tropical	Continental	NT_I NT_T	North India, Tibet	Reaches Peninsular Malaysia as upper westerlies during the Northeast monsoon
		NT_A	Australia	Reaches Peninsular Malaysia as southerlies during the Southwest Monsoon and may be confused with subsided T_{SI}
Tropical	Maritime	T_{NP}	North Pacific	Reaches Peninsular Malaysia as an extension of the Northeast Trades during the Northeast Monsoon
		T_{SI}	South Indian Ocean	Reaches Peninsular Malaysia as an extension of the South-east Trades during the Southwest Monsoon
		NT_{SP} (equator)	South Pacific	Reaches Peninsular Malaysia as easterlies modified along the equator E_M

within any one year, the time of commencement and the duration of which vary slightly with latitude and from year to year. The four seasons are: (1) the northeast monsoon (November or early December until March); (2) inter-monsoonal or transitional season (April until about May); (3) the soutwest monsoon (June until September or early October); and (4) inter-monsoonal or transitional season (October until early November). Wind and rainfall characteristics of each of the four seasons normally experienced in Peninsular Malaysia according to Dale (1956 & 1959) are given in Table 3. Characteristic features of other climatic elements by seasons, however, are not available. Figure 9 shows the surface winds which blow over Southeast Asia and the position of the airstream boundaries for January, April, July and October.

These seasonal changes are very different from those which might be expected from the planetary circulation pattern. When they are well-developed, the monsoons dominate the circulation over a wide area. As rainfall over most of Southeast Asia is in some way connected with the monsoons, the time of their onset and retreat concerns nearly all the inhabitants of the region. Aspects of the northeast monsoon floods in Peninsular Malaysia have been discussed by Gan (1962), Chia (1970) and more recently by Sham (1973a).

This summary of the circulation patterns, the existence of the different seasons of the year and the dominance of the monsoons sets the basic form of Kuala Lumpur - Petaling Jaya climate and will serve as a foundation for the detailed analysis of individual elements which follow.

TABLE 3

Wind and Rainfall Characteristics of Each of the Four Seasons Normally Experienced in Peninsular Malaysia According to Dale (1956 & 1959)*

Climatic variable	Northeast Monsoon (Nov. or early Dec.-Mar.)	Intermonsoonal (Apr.-May)	Southwest Monsoon (Jun.-Sep. or early Oct.)	Intermonsoonal (Oct.- early Nov.)
Surface wind	Northeasterly winds whose speeds seldom exceed 21.0 knots (10.8 ms^{-1}).	Either weak and variable, or reduced to a calm.	Southwesterly winds. Generally weaker than the northeasterlies and are often subordinate to land and sea breezes in coastal districts.	Either weak and variable, or reduced to a calm.
Rainfall	Over most of Peninsular Malaysia the general pattern of the wind seasons is reflected in the rainfall regime. The relationship varies, however, from place to place. In many parts a rainfall maximum coincides with each of the two transitional periods, and a minimum occurs sometime during each of the two monsoons. In other parts there may be only one maximum occurring during one of the monsoons, and one minimum - occurring during the other monsoon. There are some places where one rainfall maximum occurs during a transitional season and another during a monsoon.			

* characteristic features of other climatic elements according to seasons are not available.

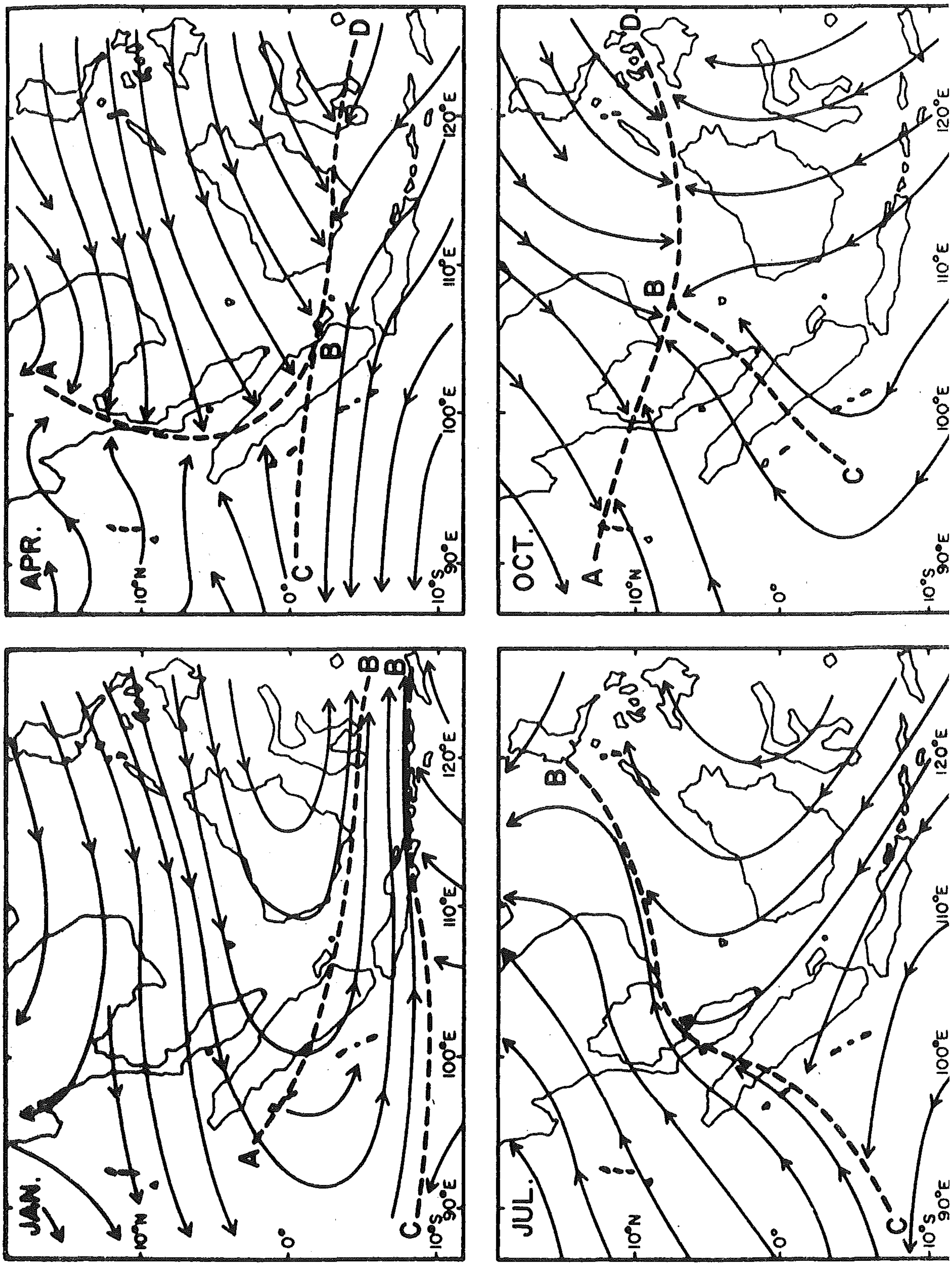


Figure 9: Low-level air currents over Peninsular Malaysia and Southeast Asia (adapted from Watts, 1955, p.10-11 and Nieuwolt, 1968, p.315)

2.4 Wind Speed and Direction

Table 4[1] shows that with the exceptions of July-September (i.e. the southwest monsoon period), the modal for the rest of the months is 0.57-1.0ms^{-1} (1.1-2.0 knots). Frequencies progressively decrease in grades away from this value but distributions in each month are characteristically skewed towards the lower speeds. Occurrences in the higher ranges are rare and there is observed prevalence of strong winds during southwest monsoon particularly in July as compared with the northeast monsoon season where very light winds are more typical.

The period June-September is observed to have relatively small number of hours of calm (Table 5a). Mean wind speeds in December are low (Table 5b) and in this month the number of hours of calm increases markedly. Other months which have high incidence of calm (over 400 hours/month) are January, April, and November. Comparison with Table 5c which gives the average number of hours per month with mean wind speed 1.5ms^{-1} (3.0 knots) and below produces similar results.

Figure 10 shows the characteristic pattern of diurnal change of the mean annual wind strength for each 60-minute period ending at an exact hour local standard time (L.S.T.). An important feature of the diagram is the relatively long period for which low wind speed predominates. The simple progression from high daytime to low night-time values of wind strength shown in Figure 10 may be related to the diurnal cycle of temperature and its effect upon the temperature lapse rate and stability of the turbulent layer.

---

1. Insofar as possible the metric units will be used from now on. However, as the Imperial units were still widely used in Malaysia when the research was done, both Metric and Imperial units will generally be shown in the text.

TABLE 4

Percentage Frequency of Average Daily Wind Speed at Subang, 1966-75

ms^{-1}	J	F	M	A	M	J	J	A	S	O	N	D	Y
0.0 - 0.5	31.6	23.4	21.9	30.7	28.4	24.7	22.6	18.1	21.3	29.7	35.3	58.1	28.82
0.6 - 1.0	50.3	48.2	45.8	47.3	32.3	30.7	15.5	31.0	32.0	32.9	39.3	34.8	36.68
1.1 - 1.5	14.8	22.0	25.2	16.0	26.5	29.3	34.2	33.6	34.7	27.1	18.7	6.5	24.05
1.6 - 2.1	2.6	6.4	5.8	5.3	10.3	13.3	18.1	14.8	8.0	8.4	6.0	0.6	8.30
2.2 - 2.6	0.7		1.3	0.7	2.5	2.0	9.0	2.5	3.3	1.9	0.7		2.05
2.7 - 3.1									0.7				0.05
$\geqslant 3.2$							0.6						0.05

(source: Malaysian Meteorological Service)

TABLE 5

Monthly Variations of Wind Characteristics at Subang, 1966-75

(a) Average number of hours of calm (< 0.5 ms^{-1})

J	F	M	A	M	J	J	A	S	O	N	D
427.1	381.0	399.5	406.1	388.4	369.4	363.8	380.2	359.3	392.8	426.2	475.4

(b) Summary characteristics of wind speed (ms^{-1})

	J	F	M	A	M	J	J	A	S	O	N	D
Mean	0.77	0.83	0.93	0.77	0.93	0.98	1.24	1.08	1.03	0.93	0.83	0.50
Median	0.72	0.88	0.93	0.77	0.93	1.03	1.24	1.03	0.98	0.93	0.77	0.50
Standard deviation	0.18	0.17	0.11	0.12	0.14	0.20	0.27	0.22	0.22	0.20	0.22	0.15

(c) Average number of hours of wind speed 1.5 ms^{-1} and below

J	F	M	A	M	J	J	A	S	O	N	D
602.6	534.2	562.5	574.6	551.3	517.0	510.4	526.8	512.6	554.3	571.0	633.9

(source: Malaysian Meteorological Service)

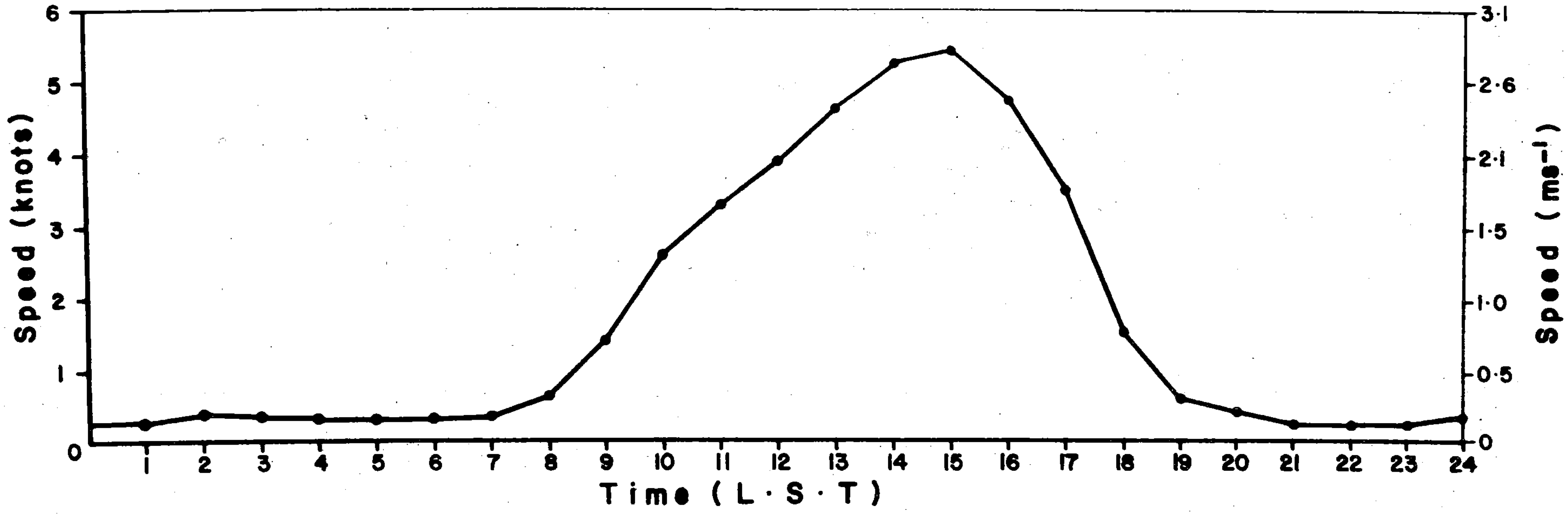


Figure 10: Average diurnal variation of wind speed at Subang, 1966-75

When the air is unstable, as during most afternoons, the air in the lowest few hundred metres is mixed, and faster-moving air is carried down, partly compensating for the effect of surface drag. In consequence, mean wind speeds and turbulence are strong. By night, the air near the ground commonly becomes more stable with much less mixing, so that frictional drag upon the lowest layers reduces near-surface wind speeds.

Changes in the patterns of wind direction for speeds greater than $1.5ms^{-1}$ (3.0 knots) and $0.5ms^{-1}$ (1.0 knot) are given in Figure 11. Over the year as a whole the prevailing winds are from WSW - NNW making up 40 to 45 percent of all measured wind directions. Winds from SE - SW also show relatively high frequency while those from N - E are the lowest.

2.5 Radiation and Sunshine

The mean seasonal variations of incoming solar radiation show a maximum in March with a secondary maximum in August (Table 6a). The low amounts of solar radiation received during November-December are due to greater cloudiness experienced with the northeast monsoon season.

Figure 12 gives the frequencies of daily values of solar radiation, by month, for the three years, 1973-75. February-April and August are observed to have relatively higher percentage of days with greater amount of radiation while the period November-December is noted to have higher percentage of days with radiation receipt of 300 $mwhr/cm^2$ and less.

Figure 13 indicates that the average intensities of solar radiation increase relatively sharply after sunrise and decrease somewhat less rapidly during the afternoon. Maximum solar

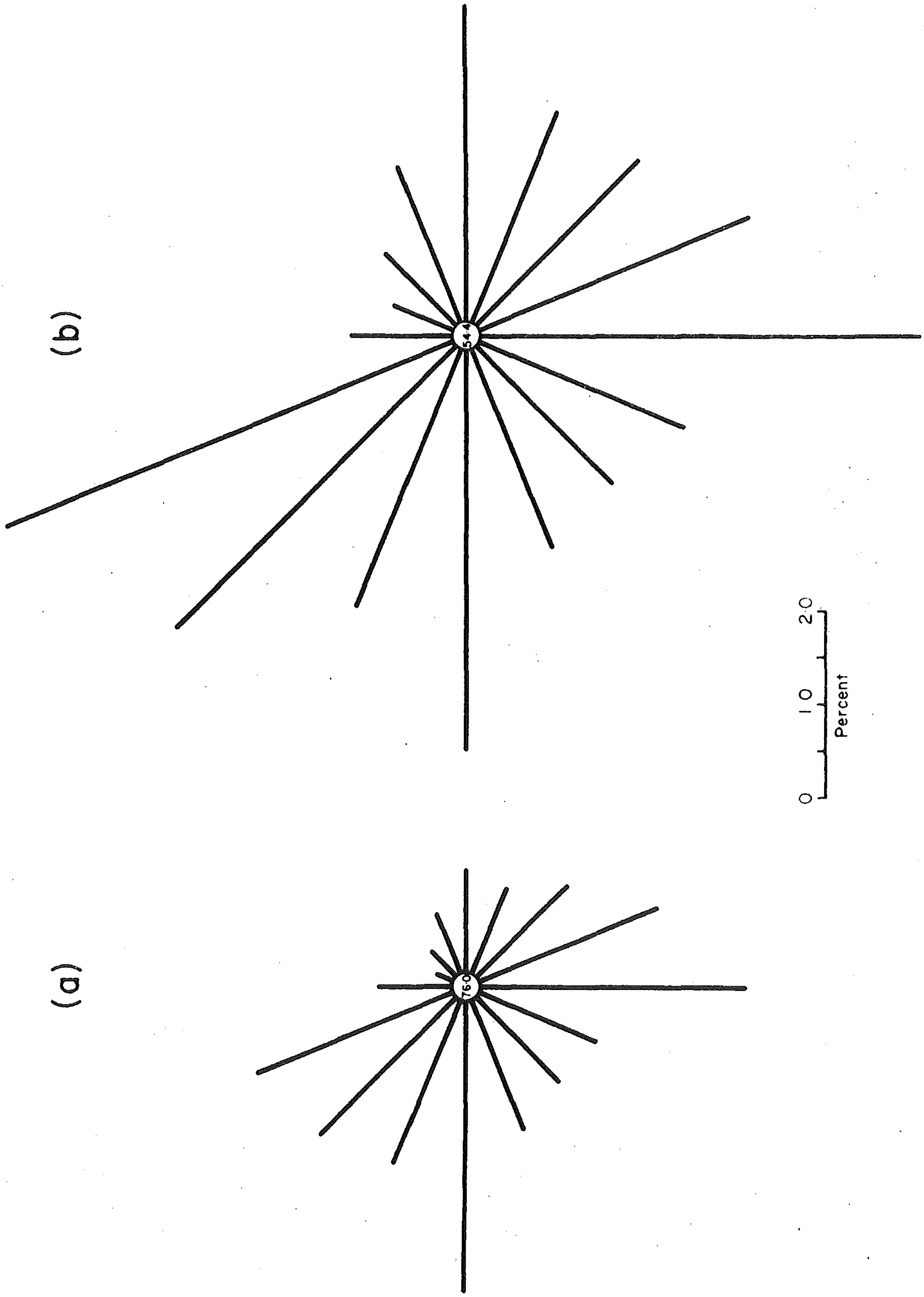


Figure 11: Percentage frequency of winds (a) of more than 1.5ms^{-1} (3.0 knots); and (b) of more than 0.5ms^{-1} (1.0 knot) at Subang, 1966-75. Figures in the centre circles indicate the percentage of winds less than 1.5ms^{-1} (3.0 knots) and less than 0.5ms^{-1} (1.0 knot) respectively

TABLE 6

Average and Extreme Values of (a) Total Daily Solar Radiation ($mwhr/cm^2$) (1973-75); and (b) Sunshine Duration (hours) (1966-75) by month, at Subang

	J	F	M	A	M	J	J	A	S	O	N	D	Y
Max.	565.12	642.98	694.58	626.49	594.35	577.50	612.49	631.36	580.08	620.39	546.73	580.52	606.05
Min.	507.48	480.06	526.09	518.35	492.45	463.29	461.20	522.36	501.00	498.55	410.63	441.60	485.26
Mean	532.32	571.22	616.89	582.19	560.09	530.93	554.99	592.52	551.25	561.92	499.21	515.68	555.77

	J	F	M	A	M	J	J	A	S	O	N	D
Average	190.8	189.2	220.8	202.1	208.7	188.9	198.5	189.8	166.7	172.8	149.3	157.1
Highest	219.3	234.2	261.6	234.6	225.7	210.5	223.1	223.0	205.7	193.9	199.8	189.6
Lowest	156.8	151.4	196.5	188.0	182.5	170.6	175.8	160.3	146.2	145.7	111.9	134.5

(source: Malaysian Meteorological Service)

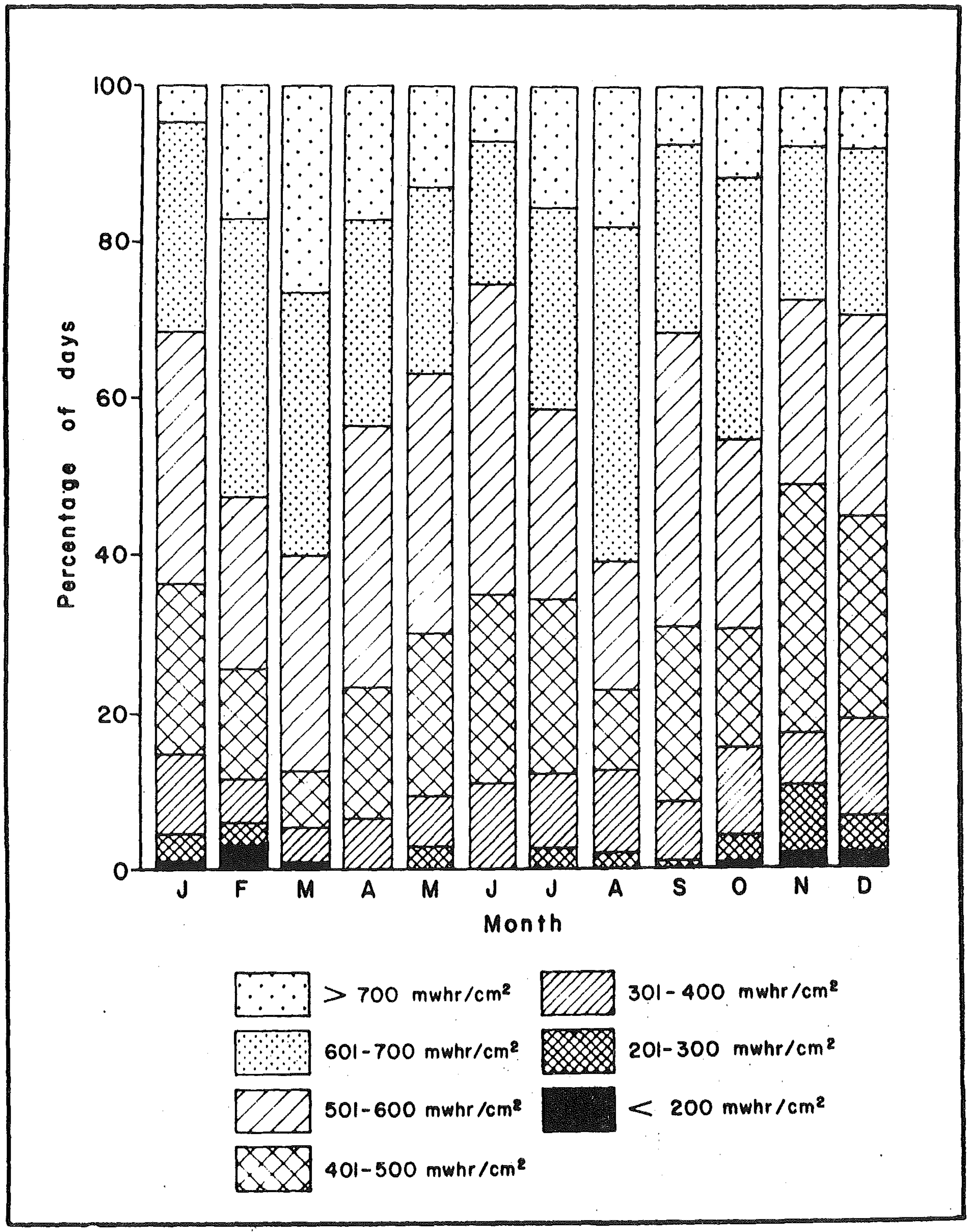


Figure 12: Seasonal variations in the percentage of days with various amounts of solar radiation values at Subang, 1973-75

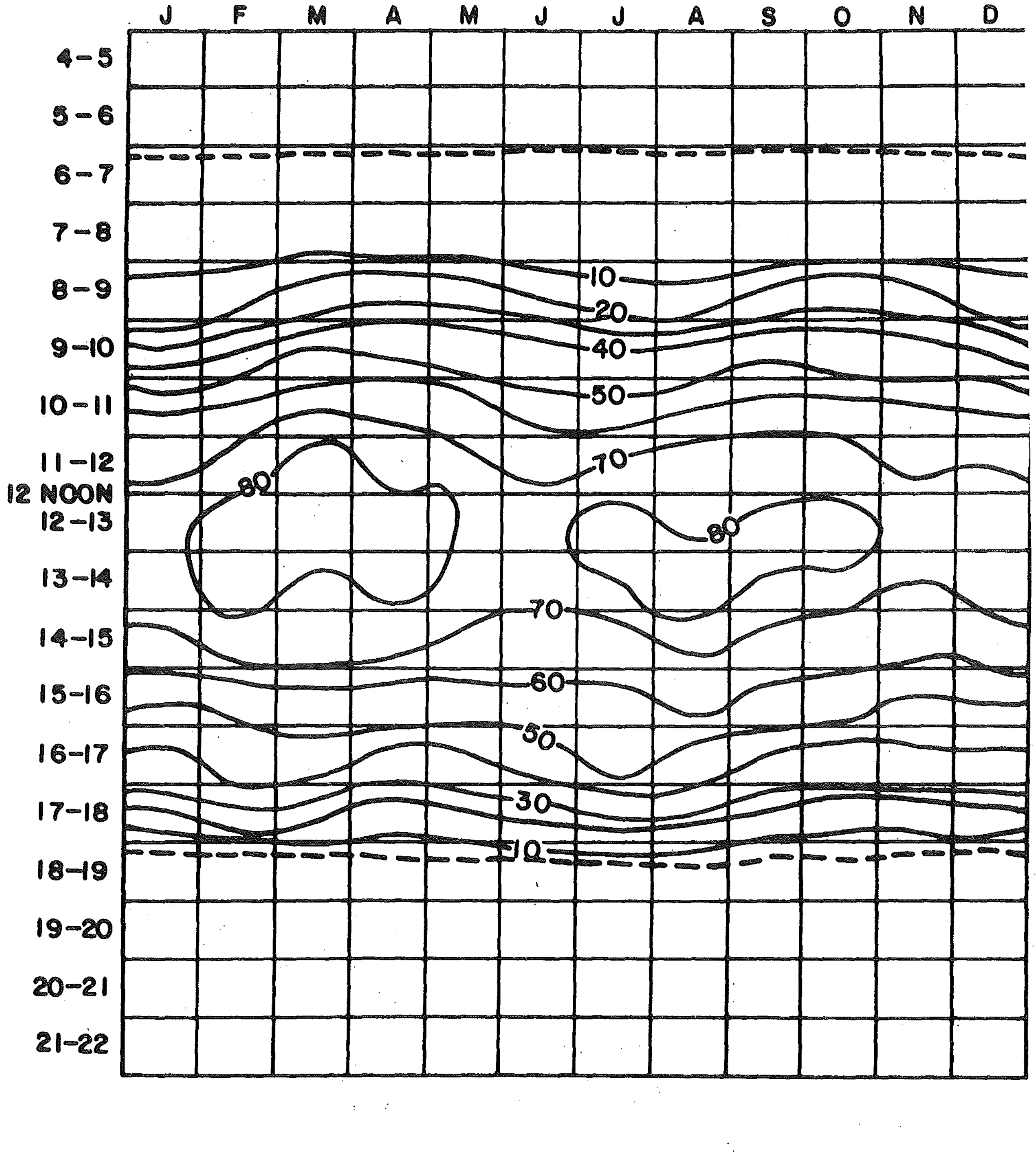


Figure 13: Average hourly totals of radiation ($mwhr/cm^2$) Subang, 1973-75. Broken lines indicate the times of sunrise and sunset

radiation receipts are experienced between 1200 and 1400 hours (L.S.T.) in all the months except December. This is some two hours after the time of maximum duration of sunshine (Sham, 1973b). Chia (1969) found a similar pattern in Singapore although the time of maximum receipt of radiation there was one to two hours earlier compared to that of Subang.

Generally sunshine amounts are higher from January to August and lower for the rest of the year with values consistently below 6.0 hours/day (Figure 14). The monthly averages of bright sunshine in Table 6b shows a similar pattern with the highest peak occurring in March in all the three cases of the average, highest and lowest values. The month-to-month changes however are more 'jagged' although the generally downward trend towards the end of the year is still evident.

The generally higher sunshine values from January to August and lower values during the rest of the year is also evident when the percentage of days with various amounts of sunshine are examined (Figure 15). Completely overcast days are most frequently experienced during December-January which coincides with the northeast monsoon season.

Figure 16 shows the diurnal variation of sunshine for Subang, 1966-75. The rapid increase in amounts of sunshine from the time of sunrise to the period of maximum sunshine applies throughout the year especially after 0630 hours (L.S.T.). Thereafter average sunshine amount decreases unevenly during the year. With the exception of July and December, maximum sunshine is received between 1000 and 1200 hours (L.S.T.)

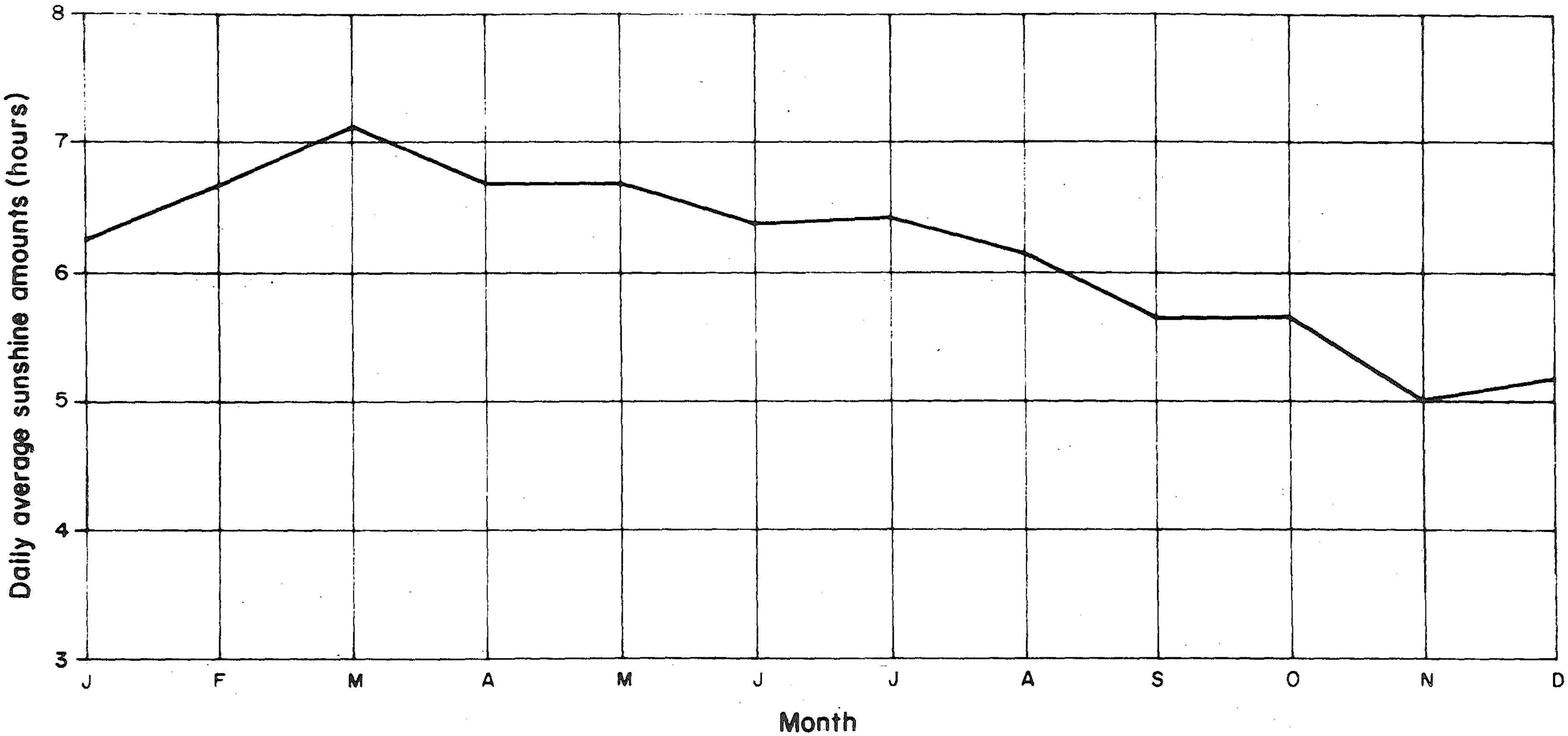


Figure 14: Variations of monthly average sunshine per day for Subang, 1966-75

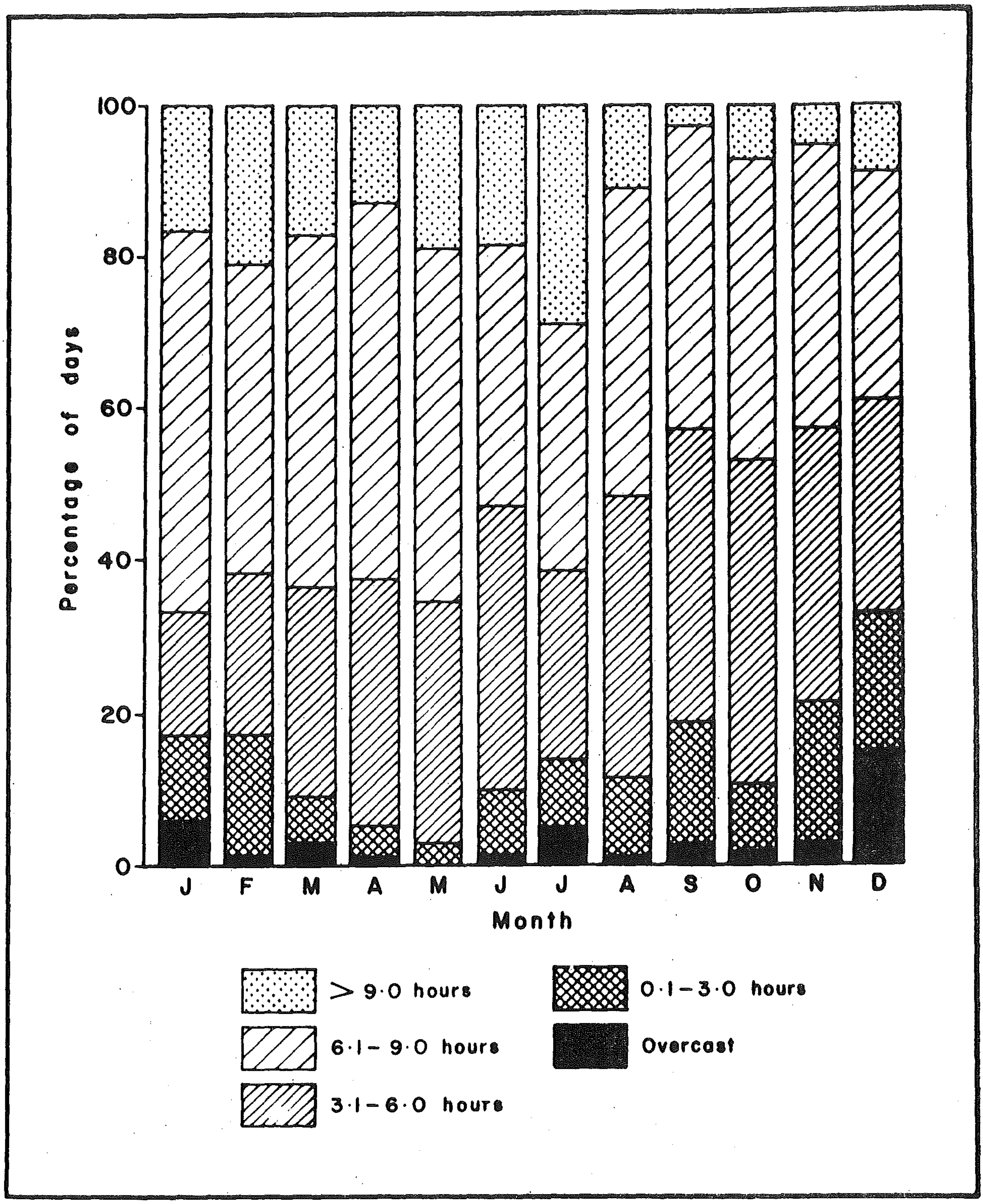


Figure 15: Seasonal variation of the percentages of days with various amounts of sunshine for Subang, 1966-75

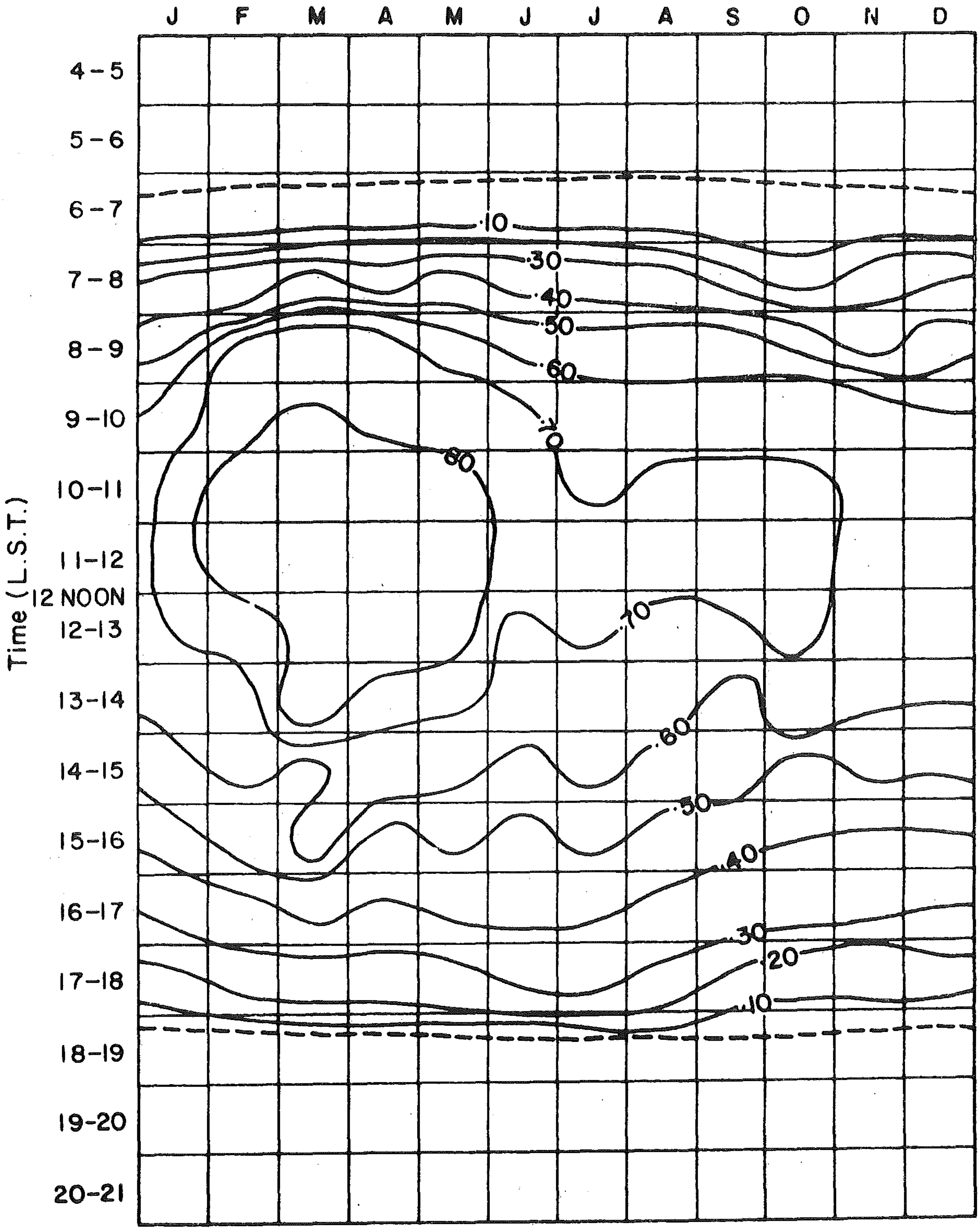


Figure 16: Average hourly totals of bright sunshine at Subang, 1966-75. Figures are in tenth of an hour. Broken lines indicate the times of sunrise and sunset

2.6 Temperature

Figures 17, 18, and 19 show the day-to-day variations of average maximum, minimum, and mean temperatures respectively. In general, the average and extreme daily maximum temperatures vary from high values during March-May to low during December-January. This compares well with the average condition for the Philippines where the hottest months are during April-June and the coldest months are during December-February (Flores & Balagot, 1969). The day-to-day departures of the highest maximum temperatures are observed to be relatively small compared to those of the lowest maximum temperatures where they can be quite substantial. For the average and extreme minimum temperatures, the absolute range is substantially smaller than that of the maximum temperatures. Nevertheless the apparently higher and lower values during March-May and December-January respectively are still evident. Another feature of the average and extreme minimum temperatures is the relatively more even day-to-day departures which apply to both the average and extreme values.

The graph of mean temperatures, whilst of less immediate use as an indication of actual conditions, gives a convenient expression of the general day-to-day trends. As such, this measure has been used by a number of workers in investigations of long-period climatic trends and singularities (e.g. Buchan, 1869; Brooks & Mirrlees, 1930; Chandler, 1965). Figure 20 shows the 5-day smoothed mean temperatures, 1966-75. The period covered by the present data is too short, however, for any definite conclusion to be reached with regard to trend singularities. Nevertheless, a number of interesting features may be noted: (1) although the diurnal range can exceed 11.1°C (20°F), the mean values tend to

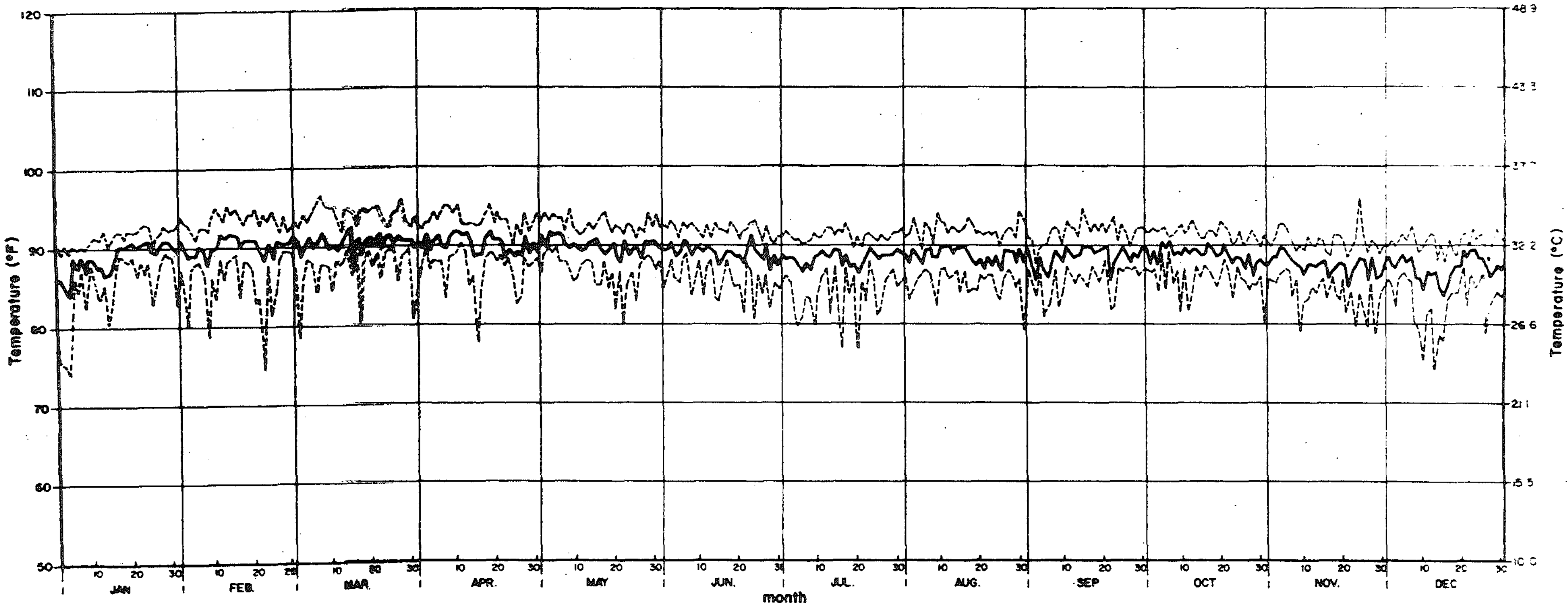


Figure 17: Average and extreme daily maximum temperatures at Subang, 1966-75. Extremes are shown by broken lines

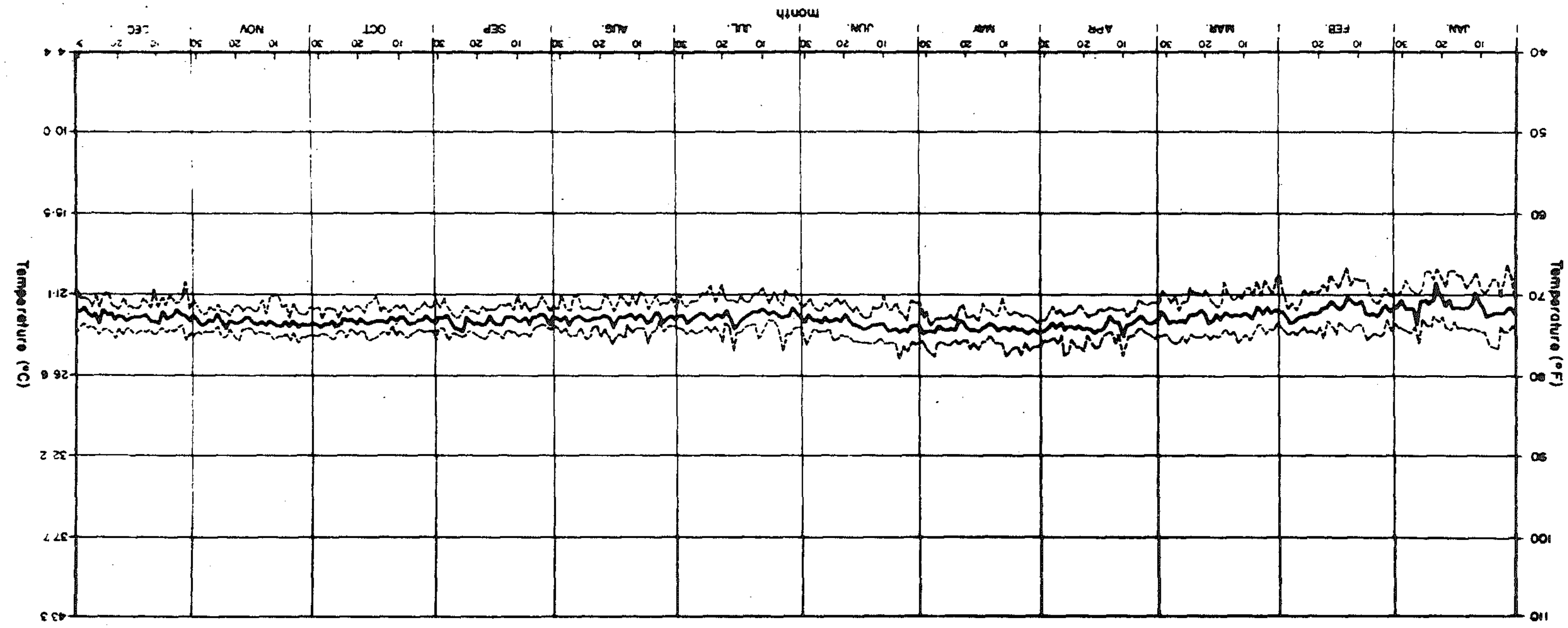


Figure 18: Average and extreme daily minimum temperatures at Subang, 1966-75. Extremes are shown by broken lines

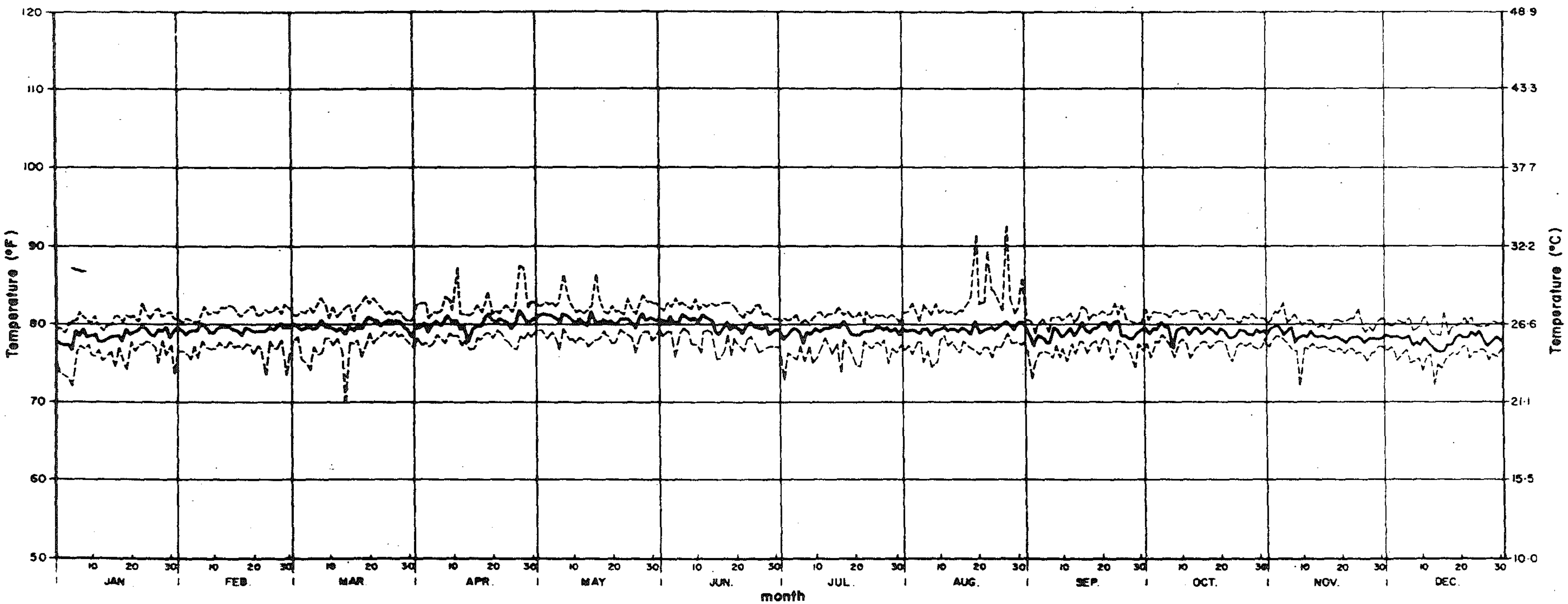


Figure 19: Average and extreme daily mean temperatures at Subang, 1966-75. Extremes are shown by broken lines

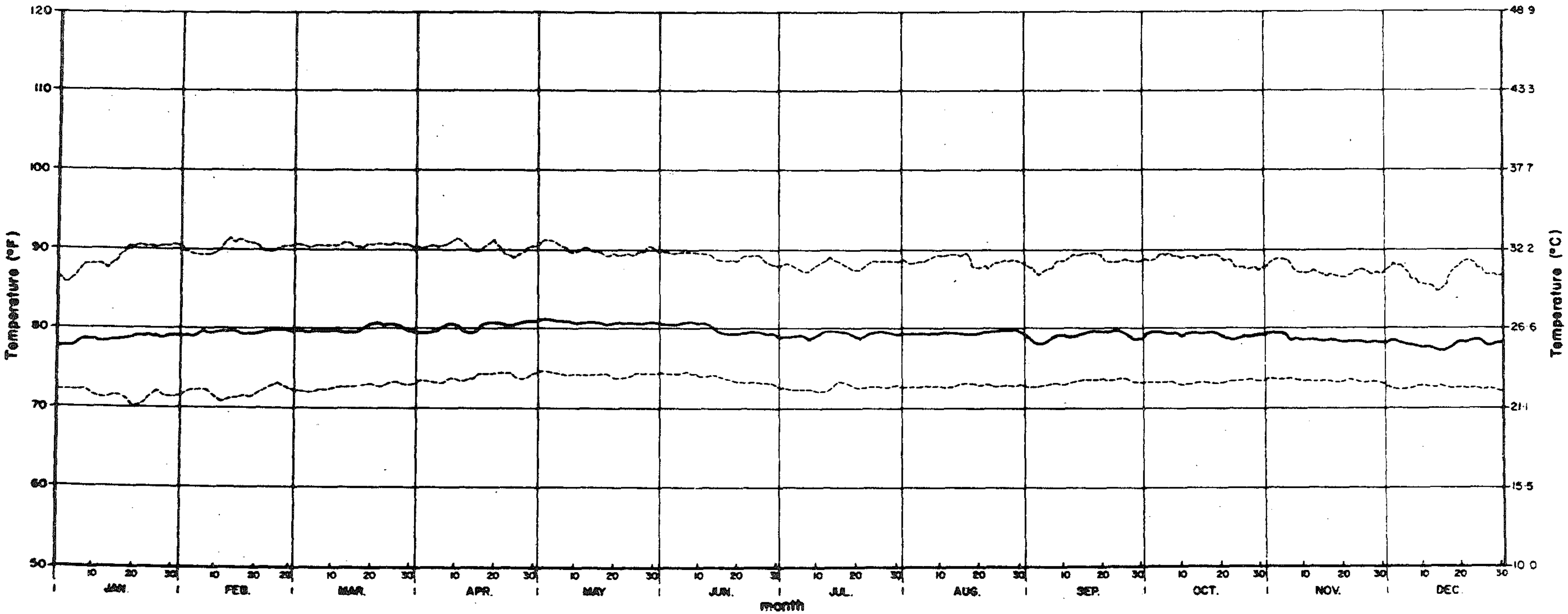


Figure 20: Smoothed mean daily maximum, minimum and mean temperatures at Subang, 1966-75 (5-day moving mean)

oscillate between 25.3°C and 27.2°C (77.5°F and 81.0°F); (2) there appears to be a kind of 'warm spell' from mid-March to about mid-June coinciding with the transitional period immediately after the northeast monsoon season. Thereafter the temperature decreases slightly and remains steady throughout the rest of the seasons until about beginning of February when it starts to increase again; (3) in general, the daily changes in maximum temperature are more 'jagged' compared to those of either minimum or mean temperatures. Nevertheless the apparently warm period between mid-March to about mid-June is still evident.

The average hourly temperature at Subang (Figure 21) indicates that (1) a fairly rapid rise in temperature takes place during the first six or seven hours of daylight, after reaching the maximum the temperature falls again, fairly rapidly in the late afternoon and slowly through the night; (2) generally the highest temperatures occur between 1300 and 1500 hours (L.S.T.) for all the months. No apparent lag in the times of occurrence was observed during any of the months; and (3) minimum temperatures occur fairly consistently between shortly before dawn and 0700 hours (L.S.T.).

One distinctive feature of most tropical climates is that average daily range of temperature exceeds average annual range. For Kuala Lumpur - Petaling Jaya these are 8.9°C (16°F) and 1.4°C (2.4°F) respectively. Lockwood (1974, p.186) reports an annual temperature range of 2.2°C (3.9°F) with a diurnal range of 6.2°C (11.2°F) for Singapore. A similar pattern was also observed by Sukanto (1969) at 10 Indonesian stations located between 5°N and 10°S latitudes.

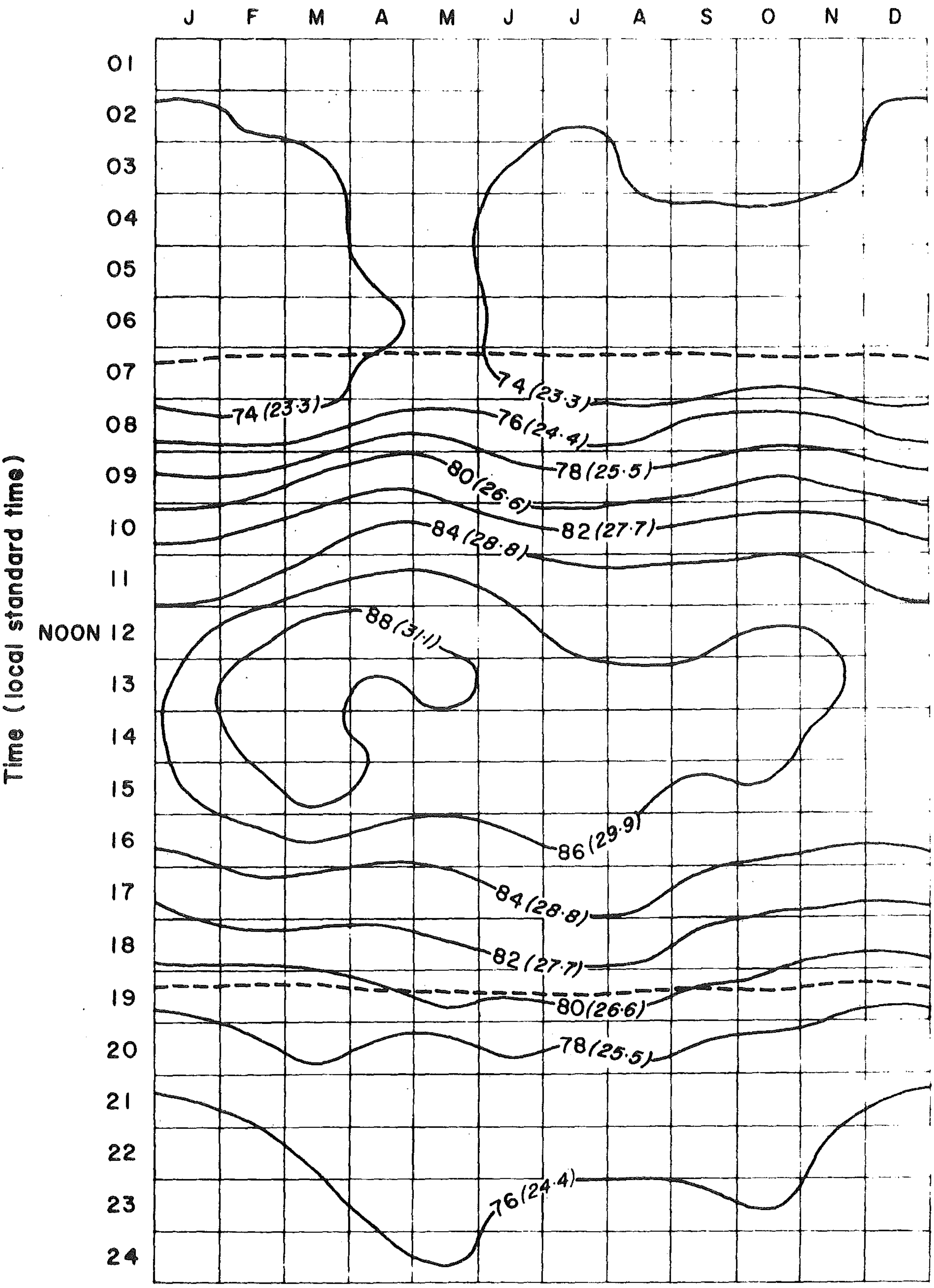


Figure 21: Average hourly temperature at Subang, 1966-75. Broken lines indicate times of sunrise and sunset. Values are given in °F with their equivalents in °C shown in brackets

2.7 Humidity

Table 7 shows the frequency analyses of daily means of relative humidity hourly readings. One very notable feature is the high percentage of high values of relative humidity during October-December which are associated with heavy rainfall amount and relatively low temperatures. Similar reasons also account for the relatively greater percentage of high values of relative humidity during April-June. Another outstanding feature shown in Table 7 is that the modal relative humidity falls, in all months, into only one 10-percent range i.e. 80.1 - 90.0 percent. February is observed to have the lowest percentage of its average daily values falling within this range. More than 35 percent of its actual average daily values fall within 70.1 - 80.0 percent range.

The day-to-day variations of relative humidity are shown in Figure 22. There is a relatively simple first order change between the months, and the mean daily values oscillate quite closely around the long-period trend values. The scatter of extreme relative humidity, particularly the maximum values during the decade follows the annual curve of mean values with a fairly constant band width. This however does not apply to the same degree in the case of minimum values.

Figure 23 indicates that the relative humidity is at its minimum between 1200 and 1300 hours (L.S.T.) and greatest slightly just before sunrise. The greatest decrease occurs between 0800 hours and 1200 hours; within this four hours a decrease of 31 percent may be recorded. A similar pattern was also reported by Flores & Balagot (1969) for 44 stations in the Philippines. Over the year, values are at a minimum, less than 56 percent, at 1300

TABLE 7

Percentage Frequency of Average Daily Relative Humidity at Subang, 1966-75

Category (%)	J	F	M	A	M	J	J	A	S	O	N	D
70.1 - 80.0	25.6	35.7	30.4	11.9	6.9	14.3	18.8	21.6	16.3	9.7	1.9	8.4
80.1 - 90.0	69.3	58.2	66.4	79.1	83.4	76.7	73.7	69.8	76.0	80.2	83.3	70.2
90.1 - 100.0	5.1	6.1	3.2	9.0	9.7	9.0	7.5	8.6	7.7	10.1	14.8	21.4

(source: Malaysian Meteorological Service)

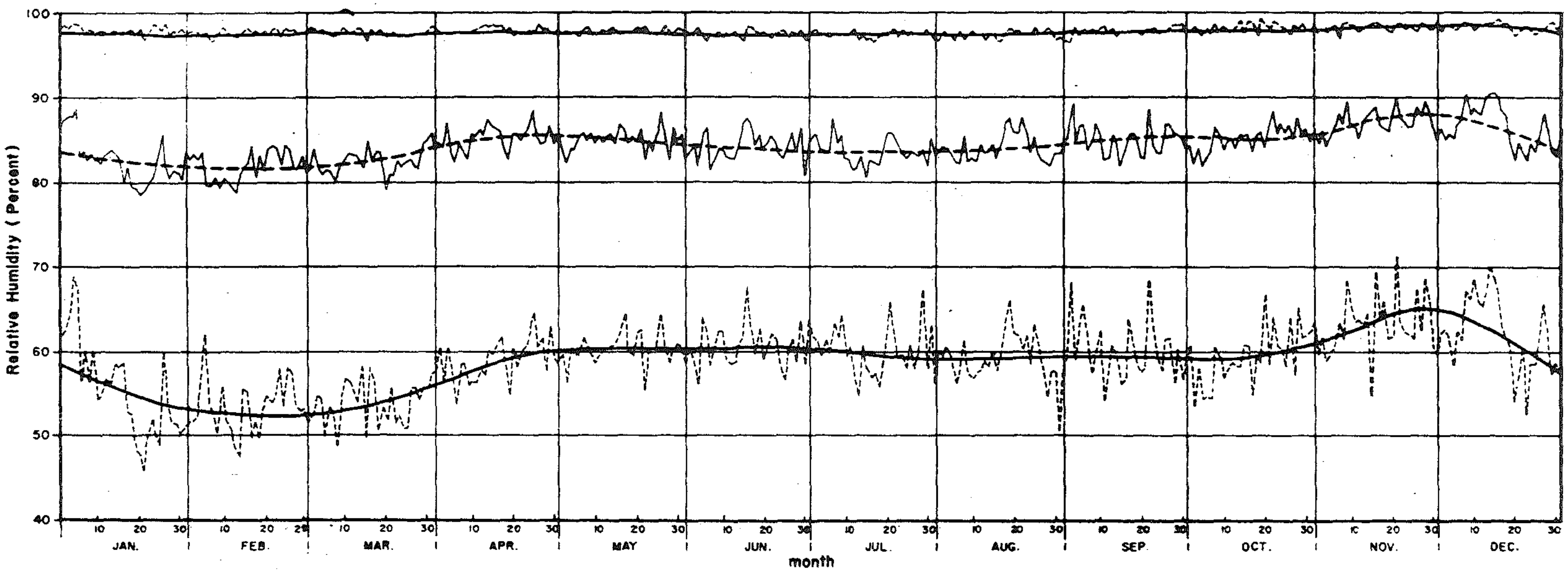


Figure 22: Average and extreme mean daily relative humidities at Subang, 1966-75. Extremes are shown by broken lines. The lines running through the respective daily values are the period trend drawn through the monthly means

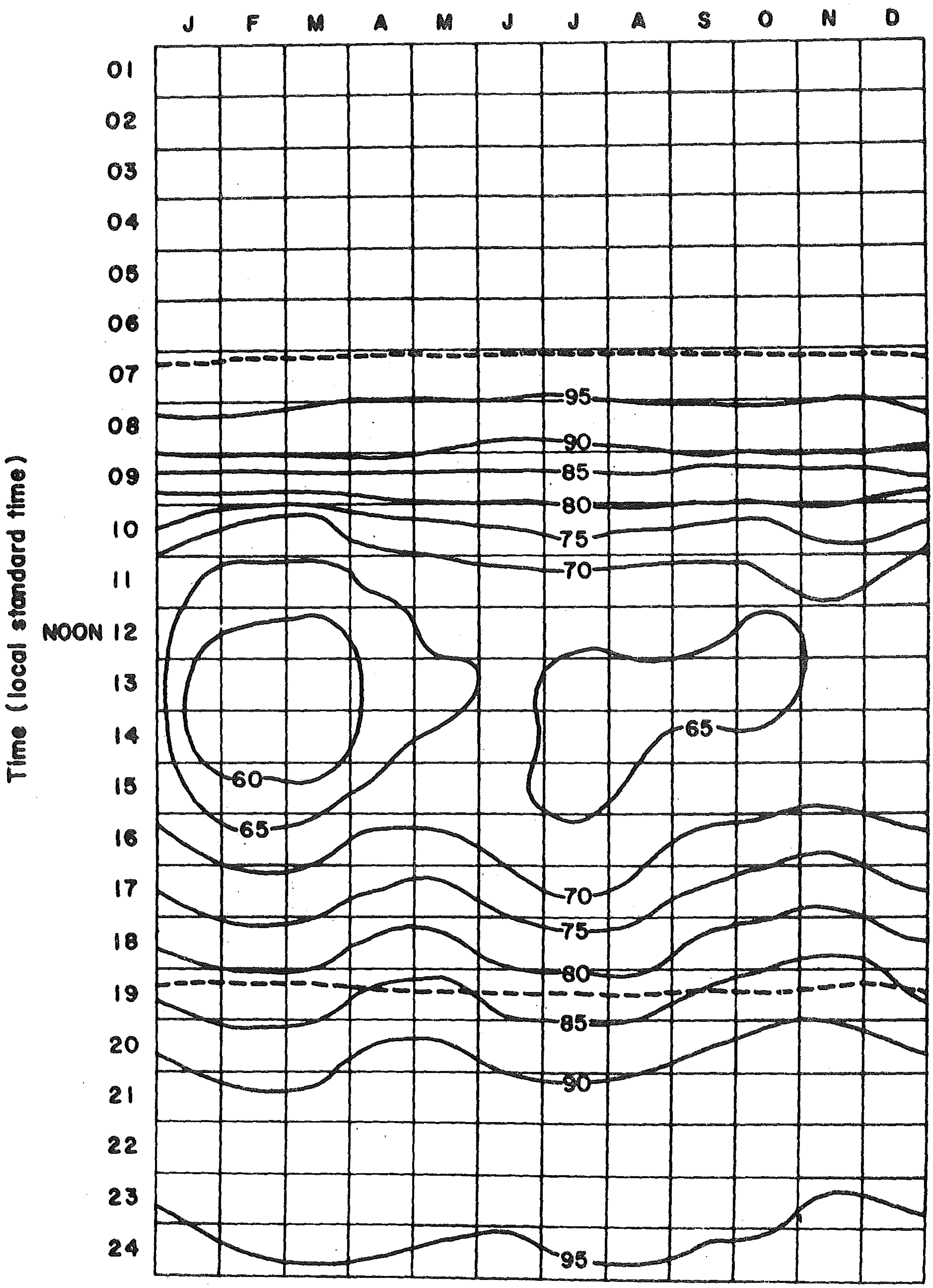


Figure 23: Average hourly relative humidities at Subang, 1966-75. Broken lines indicate times of sunrise and sunset

hours in February. This is well within the northeast monsoon season when February precipitation is only 135.89mm (5.35 inches), the third lowest, while temperatures have begun to rise. The highest average hourly value of relative humidity, 97.4 percent, occur during 0530-0630 hours in December, a month with combination of high rainfall amount (334.01mm or 13.15 inches) and generally low temperatures.

2.8 Visibility

Figure 24 shows the hourly frequency of fog (visibilities less than 1000m or 1100 yards) at Subang Airport during the 1966-75 decade. The outstanding points of the variations are as follows: (1) A high frequency of fog occurrences takes place about one to two hours before and soon after sunrise followed by a rapid clearance by convection one hour or so after sunrise; (2) Fog rarely occurs between 0800 and 0100 hours (L.S.T.). Its development normally takes place between 0300 and 0700 hours coinciding with a period which generally has high humidity values; (3) A maximum frequency of fog occurs between 0600 and 0700 hours in October with July on the average having the least number of fogs. The least number of fog occurrences in July could probably be due to the relatively windy and dry period during this month; and (4) The period October-January and April on the average have a high frequency of fog occurrences which are well over 100 hours each.

The occurrence and severity of fogs is closely controlled by the general synoptic situation. There is a tendency for the maximum frequency to occur with calms and high relative humidities. Out of the total 1018 fogs recorded at Subang during 1966-75, about

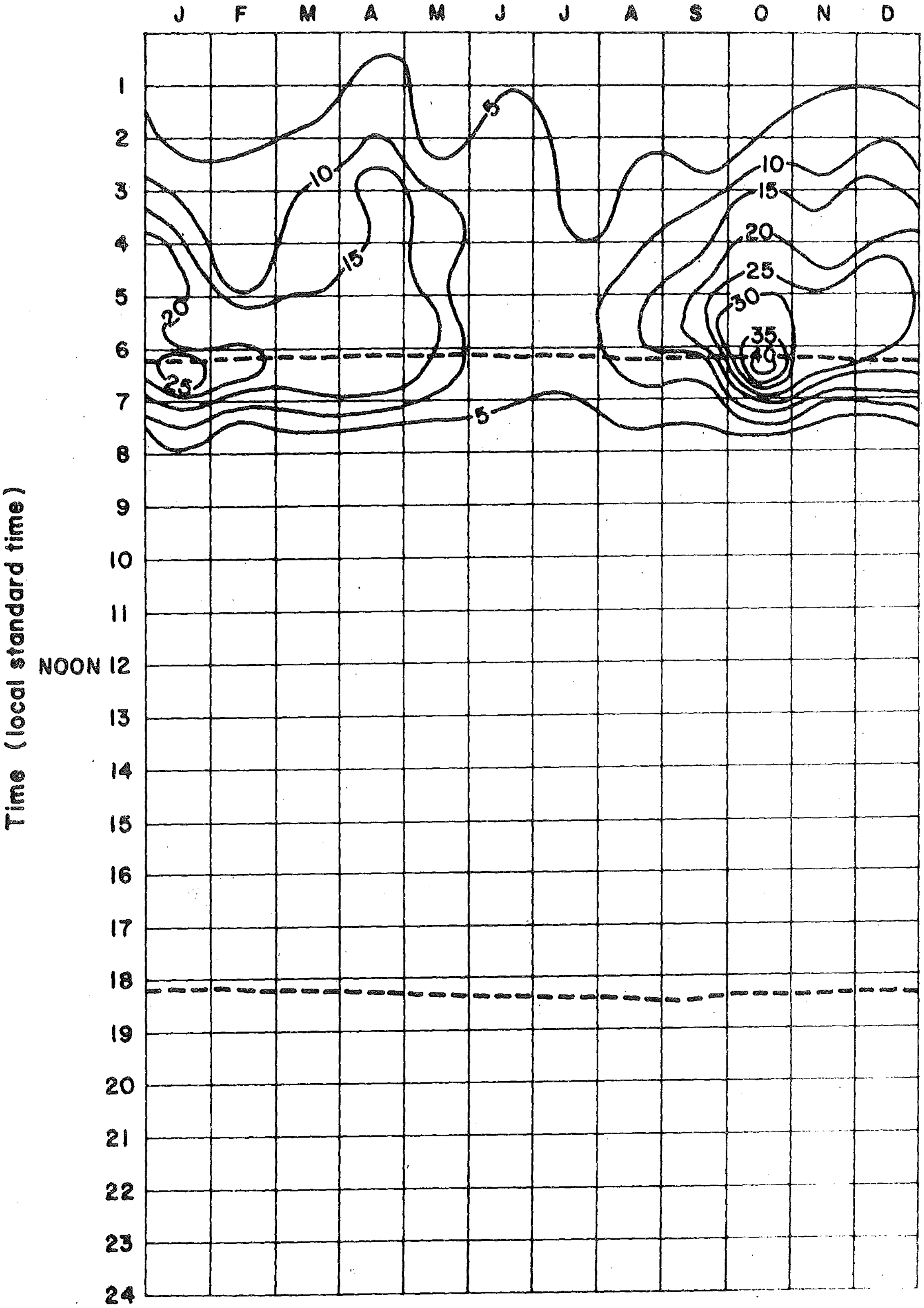


Figure 24: Hourly frequency of fog (visibilities less than 1000m or 1100 yards) at Subang Airport, 1966-75. Broken lines indicate times of sunrise and sunset

95 percent occurred with wind of 0.5ms^{-1} (1.0 knot) and less. More than 98 percent of the total 1018 fogs were observed to occur with relative humidities of 96 percent and over.

For the year as a whole, good visibilities or better i.e. visibilities of 16km (10 miles) or more, occur about 63 percent of the time (Table 8). October, December and April have a high frequency of relatively poor visibilities while the period June-July coinciding with the southwest monsoon season, has a high percentage of good visibilities.

Although for most visibility ranges, the trend is not clear, that of 32 km (20 miles) and over shows a decrease throughout the 1966-75 period (Figure 25). The percentage occurrences of visibility within this range was decreasing from 6.9 in 1966 to 1.5 in 1967 and to almost negligible from about 1968 onwards.

2.9 Cloud Amount

Cloud amounts do not generally vary greatly from one month to the next (Table 9). However, relatively clearer skies are experienced during January-February and June-July which fall within the two monsoonal periods and having among the least number of raindays. Cloudier skies, on the other hand, occur during March-April and September-December to include periods having among the highest rainfall amounts, rainfall duration and raindays.

For most months, the afternoons are more cloudy than the morning hours except during August-December which is generally cloudy throughout the day (Figure 26). A similar pattern has also been reported for Manaus in the Amazon Valley (Trewartha, 1968) and many of the stations in the Philippines (Flores & Balagot, 1969).

TABLE 8

Average Number of Hours with Various Visibility Ranges, by Month, at Subang, 1966-75

Visibility ranges	J	F	M	A	M	J	J	A	S	O	N	D	Y
0.0 - 4.0 miles (0.0 - 6.4 km)	54.7	36.3	53.0	64.1	40.8	36.4	30.9	37.8	49.9	77.9	64.7	61.4	613.3
5.0 - 9.0 miles (8.0 - 14.4 km)	216.5	201.1	237.8	227.0	217.9	188.2	204.9	203.1	213.1	226.7	226.6	241.3	2624.0
10.0 - 14.0 miles (16.0 - 22.4 km)	202.5	187.4	192.4	186.1	206.0	222.6	222.9	231.9	208.0	190.5	189.0	189.0	2450.7
15.0 - 19.0 miles (24.0 - 30.4 km)	256.4	231.7	251.4	230.2	268.3	269.9	282.5	268.3	247.4	247.2	240.7	248.5	3070.4
20 miles & above (32 km & above)	13.9	15.5	9.4	12.6	11.0	2.9	2.8	2.9	1.6	1.7	3.0	3.8	81.0

(source: Malaysian Meteorological Service)

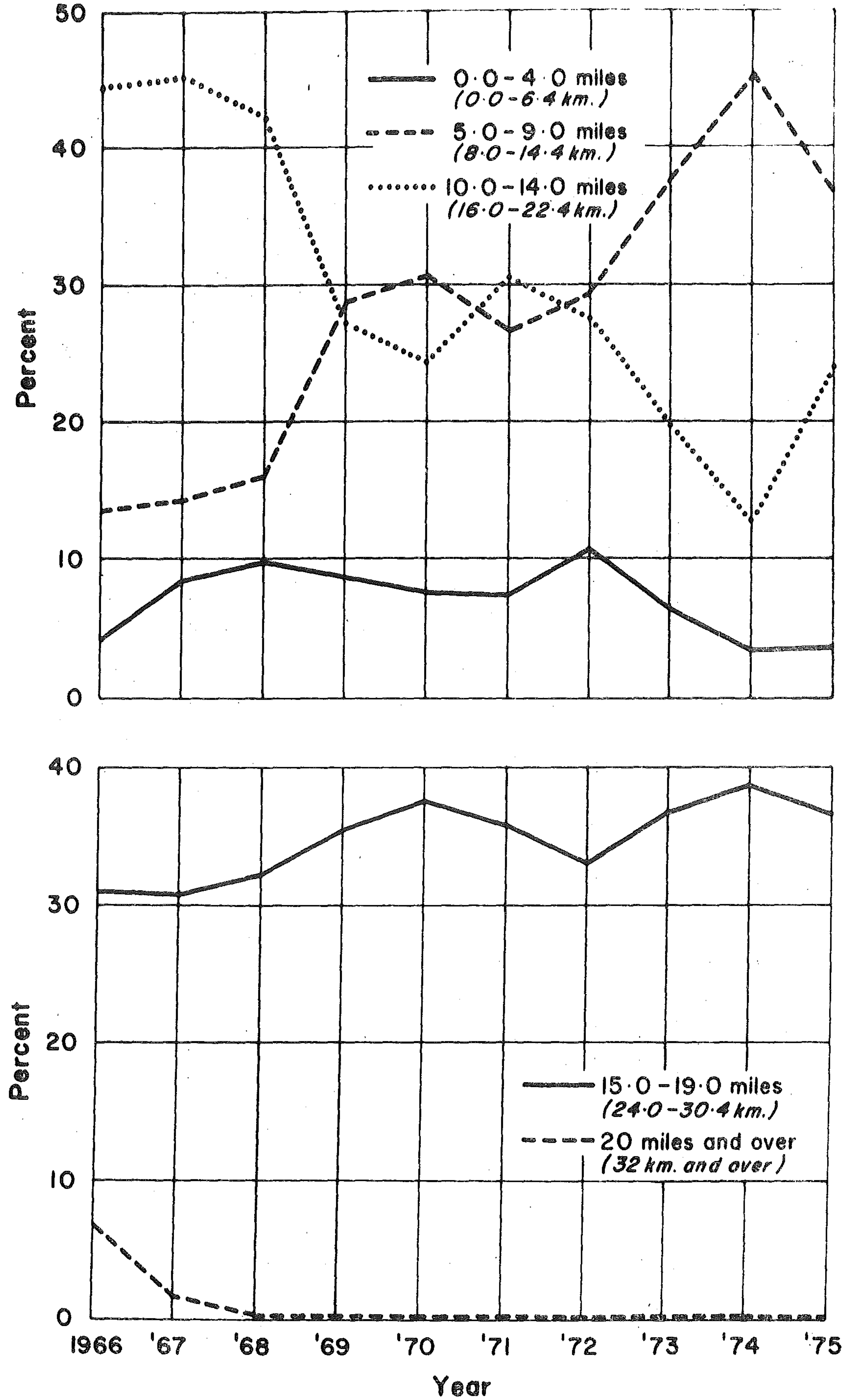


Figure 25: Percentage number of hours with various visibility ranges, by year, Subang, 1966–75

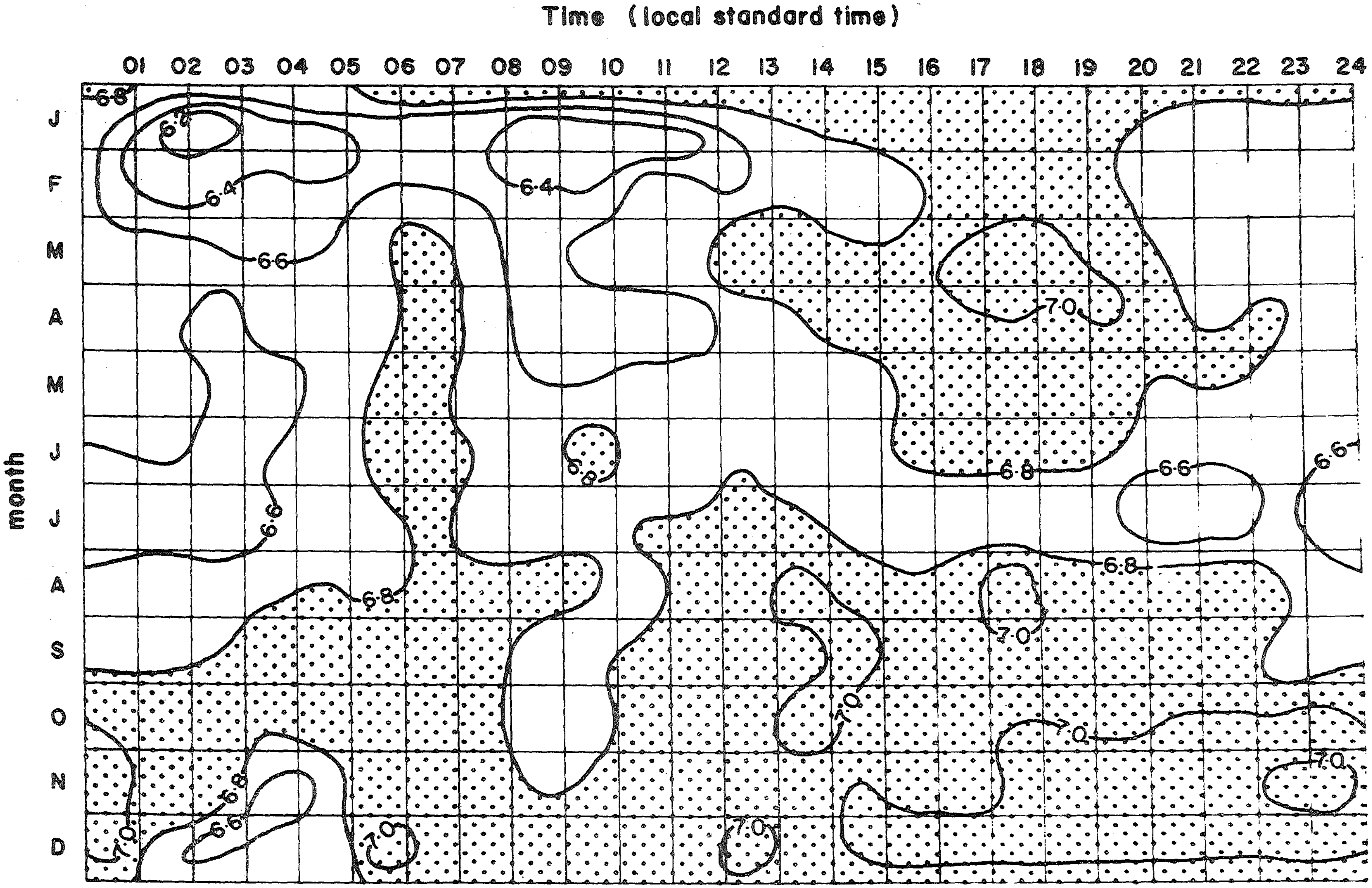


Figure 26: Average hourly cloud amount (oktas) for Subang, 1966–75

TABLE 9

Average monthly cloud amount (in Oktas) at Subang, 1966-75

J	F	M	A	M	J	J	A	S	O	N	D	Y
6.2	6.6	6.9	6.8	6.7	6.6	6.6	6.7	6.9	6.8	7.0	7.0	6.7

(source: Malaysian Meteorological Service)

Figure 27 shows that generally cloud amounts range from 6.6 to 6.9 oktas with two minima followed by two maximum periods. The build-up in cloud amount during 1700-2000 hours coincides with (1) the period when thermal activities and turbulence are at their greatest; and (2) the occurrence of greatest rainfall amount and duration for the day. The minimum during 0200-0500 hours coincides with the period when thermals and turbulence are weak. A second cloud build-up occurs briefly between 0600 and 0700 hours before reaching another minimum during 0900-1000 hours. This could probably be attributed to the cloud build-up in the morning during the southwest monsoon months when morning rain are relatively more frequent.

2.10 Precipitation

Table 10 gives the monthly and annual averages of precipitation for the period 1966-75. If the average annual precipitation of 2596.39mm (102.22 inches) were evenly distributed throughout the year then 8.49 percent would fall in each 31-day month, 8.22 percent in each 30-day month and 7.67 (or 7.94) percent

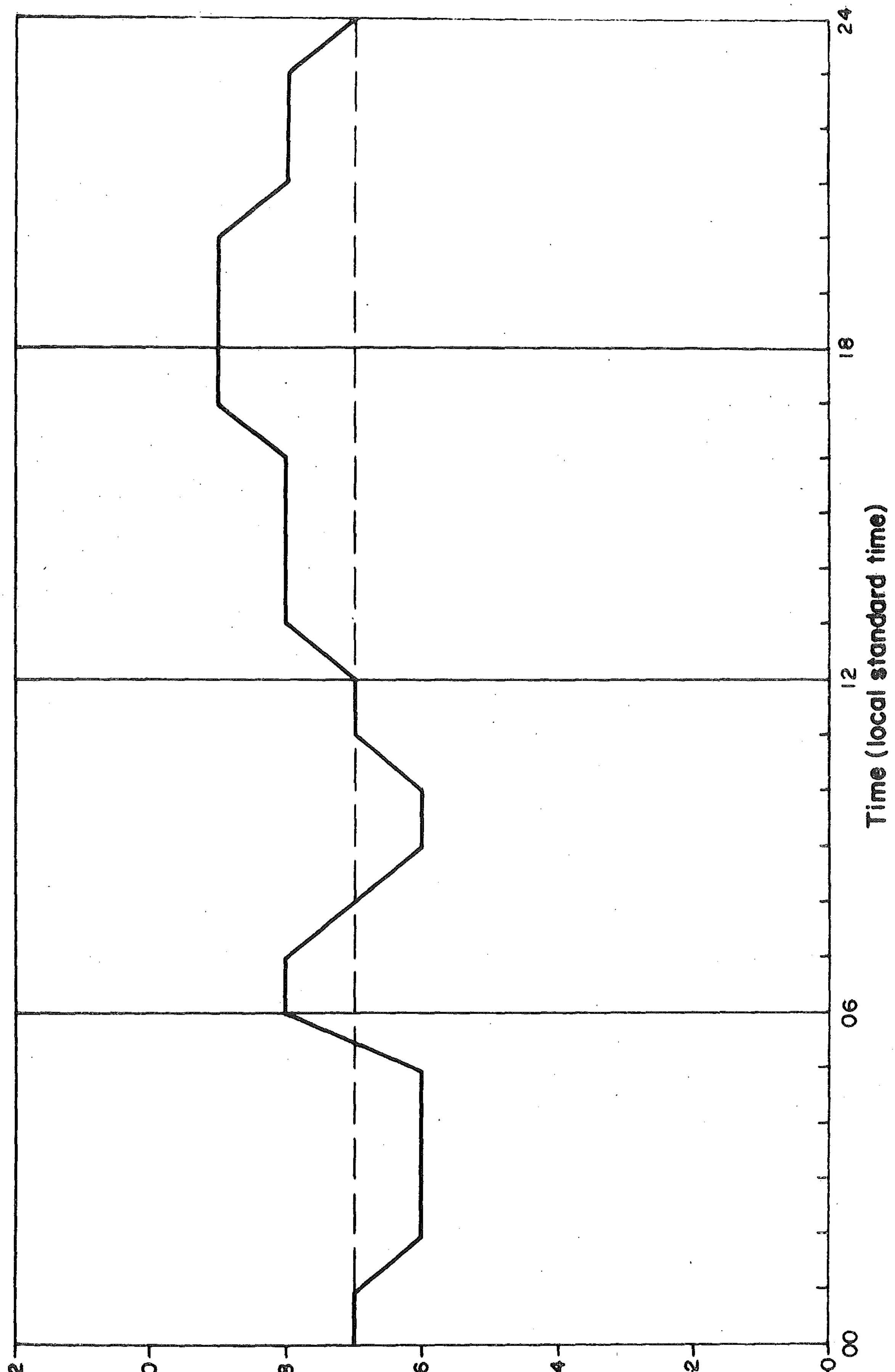


Figure 27: Average hourly cloud amount (oktas) for Subang, 1966-75. The average annual cloud amount of 6.7 oktas is shown by broken lines

TABLE 10

Monthly and Annual Averages of Precipitation at Subang, 1966-75. Figures are given in mm.

	J	F	M	A	M	J	J	A	S	O	N	D	Y
mm	205.23	135.89	164.59	328.68	246.13	167.89	118.62	202.44	127.76	349.00	216.15	334.01	2596.39
%	7.90	5.23	6.34	12.66	9.48	6.47	4.57	7.80	4.92	13.44	8.33	12.86	100.00

(source: Malaysian Meteorological Service)

in February. It will be observed then that the wettest month, October, has appreciably more than an 'even share' and the driest month, July, has very much less. Using this same form of comparison, April-May and October-December are wetter than average while January-March and June-September are drier than average. It is noted therefore that the maximum periods for rainfall receipt are the two inter-monsoonal periods and the beginning of the northeast monsoon season with the rest of the months having below average rainfall. This is reflected also in the distribution of raindays for each of the months (Table 11).

TABLE 11

Monthly and Annual Averages of Raindays
Subang, 1966-75

J	F	M	A	M	J	J	A	S	O	N	D	Y
12.8	11.3	15.2	21.0	18.8	13.2	11.5	17.2	14.3	23.7	20.5	19.7	199.2

(source: Malaysian Meteorological Service)

Dale (1960) has distinguished three patterns of diurnal rainfall in Peninsular Malaysia, i.e. the west coast type, the east coast type, and the inland type. Kuala Lumpur - Petaling Jaya as a whole has been classified by Dale as typical of inland station where the daily rainfall cycle retains the same general pattern throughout the year: the morning hours are relatively dry, especially between 0800 and 1100 hours, whilst the hours from noon until shortly before mid-night are much rainier. Figure 28 confirmed many of these features particularly the part about rainier

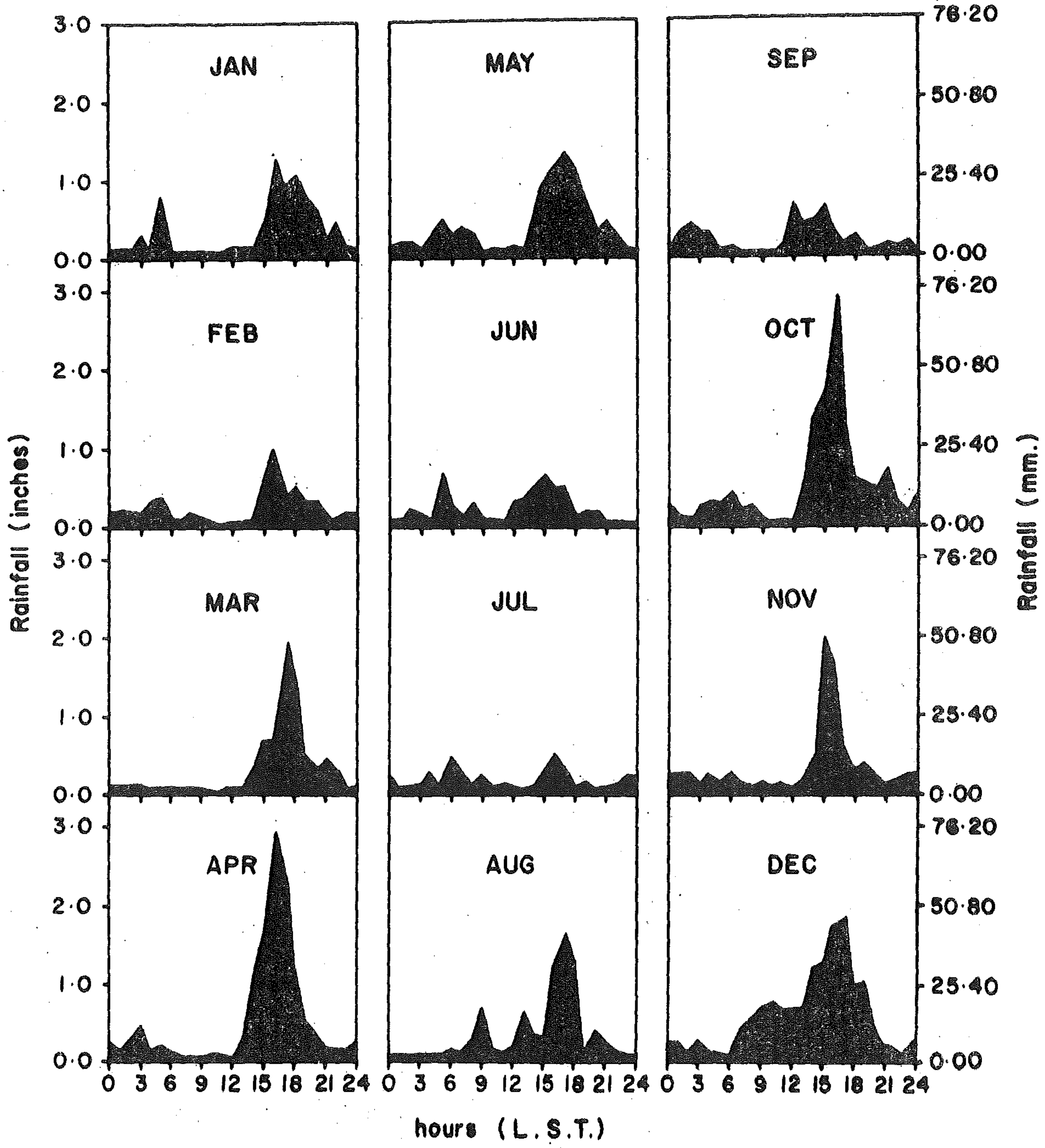


Figure 28: Diurnal variation of rainfall at Subang, 1966-75

afternoons. However, the month-to-month analyses indicate that the morning hours are far from dry especially from May to August (southwest monsoon) when quite substantial amount of rain for the day may fall during the morning hours. The morning maximum during the southwest monsoon is due, at least in part, to the development of rain bearing clouds over the Straits of Malacca during the night. These are formed by the relatively cool air of land breezes undercutting unstable air over the sea forcing the warm moist sea air to rise. Cumulonimbus clouds develop, which under the influence of the prevailing southwesterly airstream, drift landward when the land breeze dies away and bring rain to a narrow coastal belt. Such showers have been said to account for the high morning frequency of rain along the west coast for several months during the southwest monsoon (Dale, 1960, p.12). The showers are often reinforced by strong squalls known as the Sumatras (Watts, 1955).

The frequency of rain increases rapidly to a peak sometime between 1400 and 1800 hours. The afternoon maximum is particularly pronounced during the early part of the northeast monsoon season and the inter-monsoonal months. Rainfall from convective storms are typical of many tropical stations. Sukanto (1969) reports that showers with an intensity of 0.5 mm/minute are common in Indonesia. The incidence of heavy falls of rain in short periods (of two hours or less) for Kuala Lumpur - Petaling Jaya is shown in Figure 29. Some of the most intense falls of rain are short-lived and although they often do a great deal of local damage, heavy rain over long periods usually leads to more widespread flooding. In Kuala Lumpur - Petaling Jaya, intense falls during afternoon thunderstorms usually cause flash floods and traffic jams in the city area especially when local thunderstorm occurrences coincide with the traffic rush in the

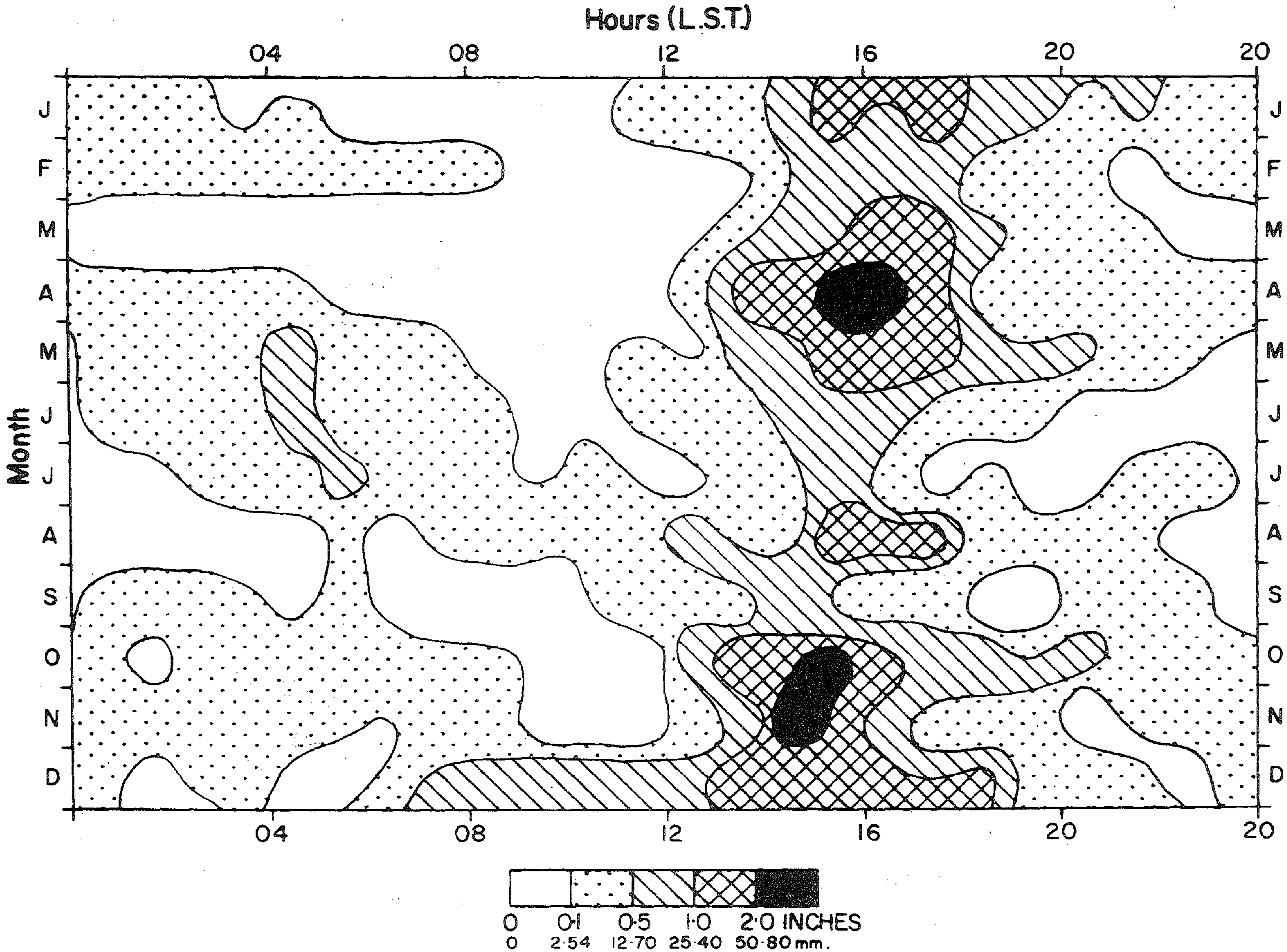


Figure 29: Diurnal variation of rainfall, by month, at Subang, 1966–75

late afternoons.

2.11 Summary of Kuala Lumpur - Petaling Jaya Climate

The discussions in sections 2.3 - 2.10 suggest that Kuala Lumpur - Petaling Jaya climate is in some way connected with the monsoons which in turn control the rainfall regime. The maximum periods for rainfall receipt are the two intermonsoonal periods and the beginning of the northeast monsoon season with the rest of the months having below average rainfall. In any one day, the hours from noon until shortly before midnight are comparatively much rainier than those of the morning. This applies almost throughout the year.

Cloud amounts do not generally vary greatly from one month to the next. However cloudier skies occur during March-April and September-December to include periods having among the highest rainfall amounts. For most months, the afternoons are more cloudy than the morning hours.

Winds are generally light throughout the year although there is a tendency for relatively stronger winds during the southwest monsoon. With the exception of late morning and the afternoon periods where winds can be strong, the rest of the day normally experiences light winds with calm conditions predominating during the night and morning.

Solar radiation, sunshine, temperatures and relative humidity are also related to the monsoons. Greater percentage of high values of relative humidity, for instance, occur during October-December while lower values of solar radiation, sunshine and temperatures are experienced during the northeast monsoon months.

2.12 Kuala Lumpur - Petaling Jaya Climate and the Tropics

Fosberg et al (1961, p.344) have defined the humid tropics as an area where (1) the mean monthly temperature for at least eight months of the year equals or exceeds 20°C (68°F); (2) the relative humidity for at least six months of the year averages 65 percent; and (3) the mean annual rainfall totals at least 1016mm (40 inches), and for at least six months precipitation is 76mm (3.0 inches) each month.

Defined in this way, the general climate of Kuala Lumpur - Petaling Jaya as based on data from Subang Airport typifies that of many areas within the humid tropics which form a discontinuous belt around the world, mainly within the confines of the Tropics of Cancer and Capricorn. It includes such areas as the East Indies, the narrow strip of the formerly French equatorial Africa, and parts of the Amazon Basin in South America (Fosberg et al, 1961, p.344).

On the basis of Thornthwaite's 1931 classification (Thornthwaite, 1933), Kuala Lumpur - Petaling Jaya experiences the tropical rainforest or the AA'r type of climate with Precipitation Effectiveness (P-E) and Temperature Efficiency (T-E) indices of 161.8 and 146.4 respectively. This climate type is found on the coast of Gulf of Mexico, along the northeastern coast of South America, along the Guinea coast of Africa, on the coast of Madagascar, along the west coast of Peninsular India and Burma, in the coastal parts of the East Indies, and in one small area on the east coast of Australia (Thornthwaite, 1933, p.437).

Thus, on the basis of both definitions, Kuala Lumpur - Petaling Jaya enjoys a climate typical of the humid tropics or the tropical rainforest of Thornthwaite. It is characterized by uniformly high temperatures and heavy annual precipitation well distributed throughout the year. The relative humidity values are high with a mean annual cloud amount of between 6.0 and 7.0 oktas. One implication of this is that many of the pollution effects of climatic variables as these are experienced in Kuala Lumpur - Petaling Jaya may well apply in the case of similar size cities experiencing the same climate type within the tropics.

2.13 Implications of Kuala Lumpur - Petaling Jaya Climate for Air Pollution

The broad features of regional macroclimate of Kuala Lumpur - Petaling Jaya have been noted. This section examines the implications of some of these features for air pollution potential within the study area particularly and for places within the tropics having similar climate type generally.

2.13.1 Atmospheric Stability, Atmospheric Ventilation, and Air Pollution Potential

Once pollutants are emitted into the atmosphere, their subsequent fate is solely a function of the prevailing weather conditions. The two key meteorological parameters which most affect the ability of the atmosphere to dilute air pollutant emissions are mixing depth and the average wind speed through the mixing layer. The mixing depth is defined as the height above the earth's surface through which relatively vigorous vertical mixing occurs (Holzworth, 1964 & 1969). The extent of a mixing depth at any particular time will depend largely on the vertical temperature structure and hence the degree of atmospheric stability. The mixing depth is reduced greatly during an intense inversion but increased during an unstable condition resulting in good dispersion and vertical transport of pollutants.

The ventilation volume which is derived by multiplying the mixing depth and the average wind speed through the mixing layer gives an indication of air pollution potential in the area (Bach, 1972a, p.26). The greater the ventilation the more pollutants are dispersed and diluted, and the smaller is the pollution hazard. On the other hand, the smaller the ventilation the less pollutants are dispersed, and the greater is the pollution hazard. Experiments of air pollution potential forecasts for the United States using mixing depth and the average wind speed through it have been described by Niemeyer (1960), Boettger (1961), Holzworth (1962), and Miller & Niemeyer (1963). A similar analysis was also undertaken for Bombay, India (Raman & Kelkar, 1972).

Data on vertical temperatures are only available from radiosondes released at Petaling Jaya. An examination of temperatures at the surface and at 1000-mb level indicates that the atmosphere is quite stable particularly in the morning (Table 12). However, this is not expected to last for very long and will eventually disappear following increase in radiation intensity and wind speed towards late morning. The percentage occurrences of inversion and isothermal situations during the evening is relatively lower although this will probably increase during the night.

Tables 13 and 14 present the monthly mean mixing depths and the average wind speed through the mixing layer for Kuala Lumpur - Petaling Jaya. Values for standard deviation and coefficient of variation are also included. Mixing depths are not measured directly but are estimated from routine meteorological observations following closely the procedures due to Holzworth (1969). A detailed

TABLE 12

Stability Conditions Based on Radiosonde Readings at the Malaysian Meteorological Service in Petaling Jaya. Figures are percentage of days in each month. Readings are taken twice daily (0730 hours and 1930 hours L.S.T.)

Stability condition	Time of readings (hours L.S.T.)	J	F	M	A	M	J	J	A	S	O	N	D	Y
Inversion	0730	42.7	30.0	29.8	16.7	18.7	25.2	33.9	26.6	17.7	14.5	9.2	16.9	23.5
	1930	5.4	4.8	4.3	10.1	9.8	6.7	4.3	3.2	2.3	3.2	4.6	7.5	5.5
Isothermal	0730	35.5	36.3	38.7	45.0	48.0	35.3	41.1	29.8	35.3	33.9	42.0	51.6	39.4
	1930	28.0	27.7	38.7	47.2	41.3	41.1	51.1	32.3	40.9	39.8	36.4	40.9	38.8
Neutral & Lapse	0730	21.8	33.7	31.5	38.3	33.3	39.5	25.0	43.6	47.0	51.6	48.8	31.5	37.1
	1930	66.6	67.5	57.0	42.7	48.9	52.2	44.6	64.5	56.8	57.0	59.0	51.6	55.7

(source: Malaysian Meteorological Service)

TABLE 13

Monthly Mean Mixing Depths at Kuala Lumpur-Petaling Jaya.
Figures are given in metres

		J	F	M	A	M	J	J	A	S	O	N	D
Morning (1972-75)	Mean	379	392	391	402	397	409	379	399	411	412	404	395
	Standard deviation	121	164	115	95	82	93	106	105	83	103	88	82
	Coefficient of variability (%)	31.9	41.8	29.4	23.6	20.7	22.7	28.0	26.3	20.2	25.0	21.8	20.8
Afternoon (1973-75)	Mean	764	914	893	552	607	655	687	789	618	645	555	582
	Standard deviation	400	712	645	333	316	276	355	437	330	246	199	248
	Coefficient of variability (%)	52.4	77.9	72.2	60.3	52.1	42.1	51.7	55.4	53.4	38.1	35.9	42.6

(source: Malaysian Meteorological Service)

TABLE 14

Monthly Mean Values of the Average Wind Speed through the Mixing Layer at Kuala Lumpur-Petaling Jaya. Figures are given in ms^{-1}

		J	F	M	A	M	J	J	A	S	O	N	D
Morning (1972-75)	Mean	0.96	1.17	1.08	1.23	1.38	1.68	1.44	1.59	1.26	1.29	1.32	0.99
	Standard deviation	0.84	1.08	0.78	0.75	0.87	1.11	1.17	0.93	0.87	1.05	1.11	0.72
	Coefficient of variability (%)	87.5	92.3	72.2	61.0	63.0	66.1	81.3	58.5	69.0	81.4	84.1	72.7
Afternoon (1973-75)	Mean	1.74	1.89	2.07	1.59	1.77	1.83	1.71	1.86	1.98	1.98	1.92	1.44
	Standard deviation	1.08	1.02	1.11	1.05	1.08	0.99	1.08	0.99	1.08	1.35	1.05	0.90
	Coefficient of variability (%)	62.1	54.0	53.6	66.0	61.0	54.1	63.2	53.2	54.5	68.2	54.7	62.5

(source: Malaysian Meteorological Service)

description of the calculation method for the study area is given in Appendix A. Morning mixing depths and wind velocities are consistently lower than the corresponding afternoon values. The coefficient of variability values are noted to be high particularly for the average wind velocities.

High concentrations of air pollution in an area are most likely to occur after several days of low mixing depth, low wind speed, and no precipitation. If this combination of circumstances occurs very frequently in an area, then it can be said that the area has a high potential for air pollution episodes. Tables 15 and 16 summarize the percentage frequency of occurrence of mean mixing depths and average wind speeds through the mixing layer by category and month in the Kuala Lumpur - Petaling Jaya area. In the National Air Pollution Potential Forecasting Programme (NAPPFP) the critical mixing depth values that have been used are 500 metres for the morning and 1,500 metres for the afternoon (National Meteorological Center, 1967). Overall, mixing depths of 900m (2970 feet) and less account for 82.8 percent of the afternoon values while 87.3 percent of the morning mixing depths fall below the critical values suggested by the NAPPFP. With regard to the average wind speeds through the mixing layers, 94.6 percent of the morning and 85.3 percent of the afternoon values are equal to or less than 3.0 ms^{-1}. The significance of these mean wind speeds may be judged from their use in the NAPPFP in which the critical value is 4.0 ms^{-1} for both morning and afternoon. The percentage frequency of occurrence of ventilation volumes by category and month for Kuala Lumpur - Petaling Jaya is shown in Table 17. The remarkably high percentage of occurrence of values below the critical limits of 2,000m^3s^{-1} (for the morning) and 6,000m^3s^{-1}

TABLE 15

Percentage Frequency of Occurrence of (a) Morning (1972-75) and (b) Afternoon (1973-75) Mixing Depths, by Category and Month

Category	J	F	M	A	M	J	J	A	S	O	N	D	Y
≤ 400m	55.7	53.1	57.3	53.3	54.0	47.1	58.1	55.6	40.3	44.4	50.4	51.6	51.8
401-450m	18.5	23.0	19.4	20.0	17.8	20.2	18.5	20.2	30.3	26.6	17.7	24.2	21.3
451-500m	14.5	8.0	7.3	11.7	16.9	17.6	14.5	12.9	16.0	15.3	19.3	16.1	14.2
≥ 501m	11.3	15.9	16.0	15.0	11.3	15.1	8.9	11.3	13.4	13.7	12.6	8.1	12.7

Category	J	F	M	A	M	J	J	A	S	O	N	D	Y
≤ 600m	38.3	39.8	45.2	69.7	60.2	44.5	48.4	34.8	54.6	50.0	67.1	65.6	51.5
601-750m	22.3	20.5	12.9	18.0	18.3	23.3	20.4	21.7	22.7	26.0	23.9	17.2	20.5
751-900m	11.7	9.6	8.6	2.2	12.9	20.0	10.8	14.1	12.5	12.0	4.5	9.7	10.8
≥ 901m	27.7	30.1	33.3	10.1	8.6	12.2	20.4	29.4	10.2	12.0	4.5	7.5	17.2

(source: Malaysian Meteorological Service)

TABLE 16

Percentage Frequency of Occurrence of Average Wind Speed through the (a) Morning (1972-75) and (b) Afternoon (1973-75) Mixing Depths by Category and Month

	Category	J	F	M	A	M	J	J	A	S	O	N	D	Y
	$\leq 1.5 ms^{-1}$	70.2	68.6	72.4	64.0	56.4	39.5	51.7	34.3	61.1	59.0	57.8	74.8	59.1
(a)	$1.6 - 3.0 ms^{-1}$	29.0	24.8	24.1	34.2	39.3	47.4	35.8	60.2	35.4	38.1	34.4	23.4	35.5
	$\geq 3.1 ms^{-1}$	0.8	6.6	3.5	1.8	4.3	13.1	12.5	5.5	3.5	2.9	7.8	1.8	5.4

	Category	J	F	M	A	M	J	J	A	S	O	N	D	Y
	$\leq 1.5 ms^{-1}$	42.5	42.7	35.4	53.2	45.5	34.2	43.0	35.3	33.8	47.6	34.2	53.3	41.7
(b)	$1.6 - 3.0 ms^{-1}$	43.8	42.7	43.9	37.7	39.0	53.2	45.3	49.4	48.6	29.8	50.7	40.0	43.6
	$\geq 3.1 ms^{-1}$	13.7	14.6	20.7	9.1	15.5	12.6	11.7	15.3	17.6	22.6	15.1	6.7	14.7

(source: Malaysian Meteorological Service)

TABLE 17

Percentage Frequency of Occurrence of (a) Morning (1972-75) and (b) Afternoon (1973-75) Ventilation Volumes by Category and Month

a)

Category ($m^3 s^{-1}$)	J	F	M	A	M	J	J	A	S	O	N	D	Y
≤ 500	62.3	52.4	63.5	50.9	44.0	30.8	56.8	36.8	55.5	53.3	57.1	68.2	52.4
501 - 1000	23.7	33.6	25.2	38.2	42.4	42.7	26.1	40.2	31.5	34.6	22.4	27.3	32.6
1001 - 1500	13.2	11.2	7.8	9.1	11.9	16.2	12.5	19.7	10.2	12.1	14.3	3.6	11.8
1501 - 2000	0.0	0.0	2.6	1.8	1.7	7.7	2.3	0.7	1.9	0.0	3.1	0.9	1.9
≥ 2001	0.8	2.8	0.9	0.0	0.0	2.6	2.3	2.6	0.9	0.0	3.1	0.0	1.3

)

Category ($m^3 s^{-1}$)	J	F	M	A	M	J	J	A	S	O	N	D	Y
≤ 1000	41.2	43.2	34.2	64.9	52.6	39.2	50.6	34.1	38.3	51.2	49.3	65.4	46.9
1001 - 2500	40.0	28.4	28.0	27.3	37.2	48.1	36.8	45.9	46.6	27.4	46.6	28.0	36.6
2501 - 4000	13.8	9.5	20.7	6.5	10.2	7.6	6.9	14.1	11.0	11.9	1.4	4.0	9.9
4001 - 6000	3.8	8.1	9.8	0.0	0.0	1.3	2.3	4.7	2.7	9.5	2.7	1.3	3.9
≥ 6001	1.2	10.8	7.3	1.3	0.0	3.8	3.4	1.2	1.4	0.0	0.0	1.3	2.7

(source: Malaysian Meteorological Service)

(for the afternoon) is once again very evident.

Comparisons of results obtained for Kuala Lumpur - Petaling Jaya with those of New York and Los Angeles are shown in Figures 30, 31 and 32. Data for New York and Los Angeles are based on those given by Holzworth (1967). In all cases, and in particular those of the average wind speed and the ventilation volume, it would appear that potential for air pollution problems in Kuala Lumpur - Petaling Jaya may be much greater than in Los Angeles. These figures also suggest that in future it might be wiser, in terms of air pollution, for any urban planning programme to take climatic factors into consideration.

It must be pointed out, however, that the method of air pollution potential forecast has up to now been entirely developed and tested in North America with mid-latitude climate experience. Its application and performance in low latitude areas have not been attempted. Because of the difference in detailed climate particularly with respect to its diurnal variation and the intensity, time of occurrence and duration of temperature inversions, it is likely that the effects of mixing depth and the wind speed through the mixing layer as they are experienced in the mid-latitude areas may not be directly comparable in the low latitude regions. However, while comparisons between tropical and mid-latitude cities may be prejudiced by the different characteristics of weather conditions and emission properties, these probably do give a first approximation of similarities or differences. The concept of air pollution potential therefore should be further explored and tested in the low latitude environment.

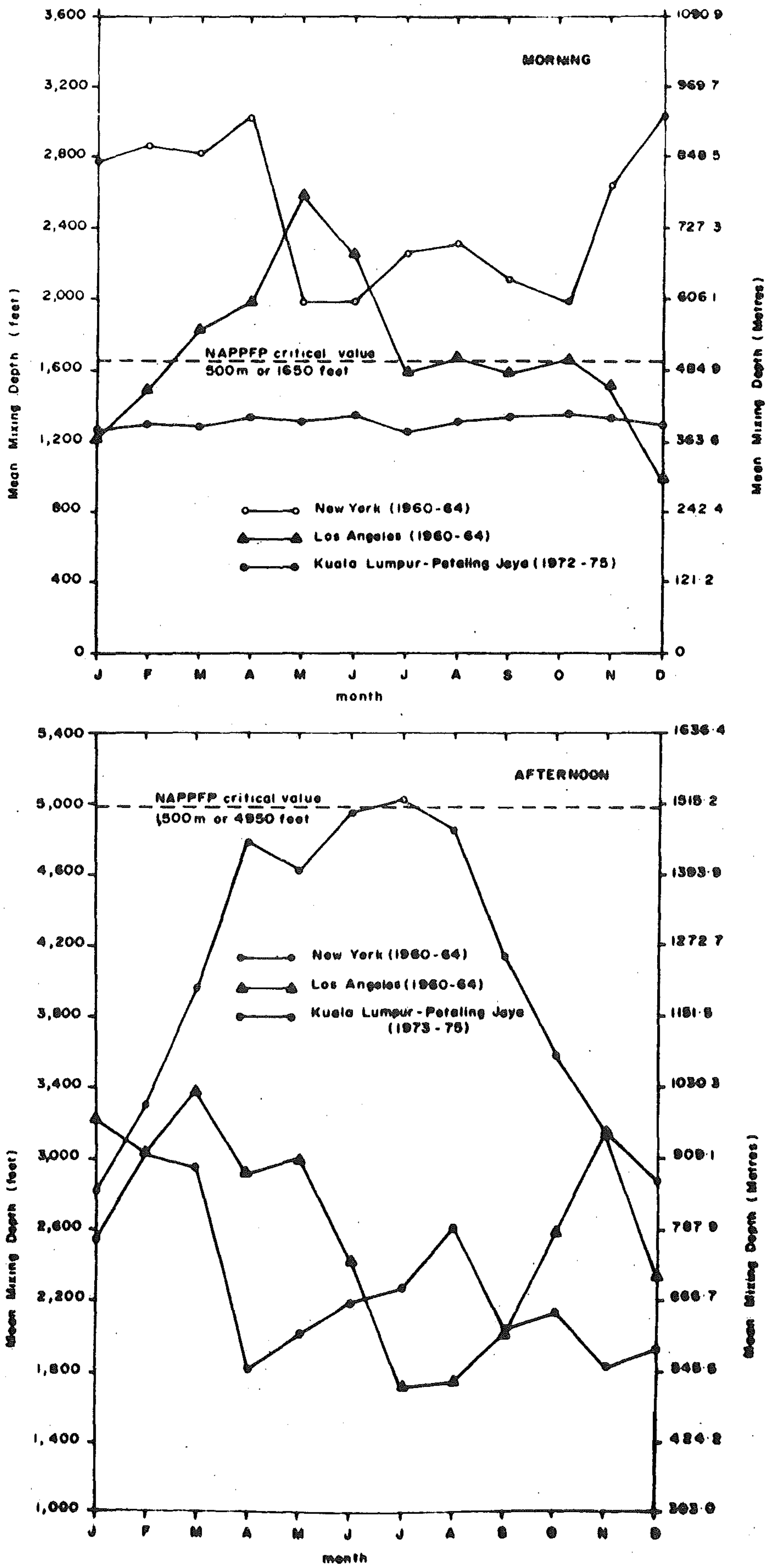


Figure 30: Monthly mean mixing depths at Kuala Lumpur - Petaling Jaya, Los Angeles and New York

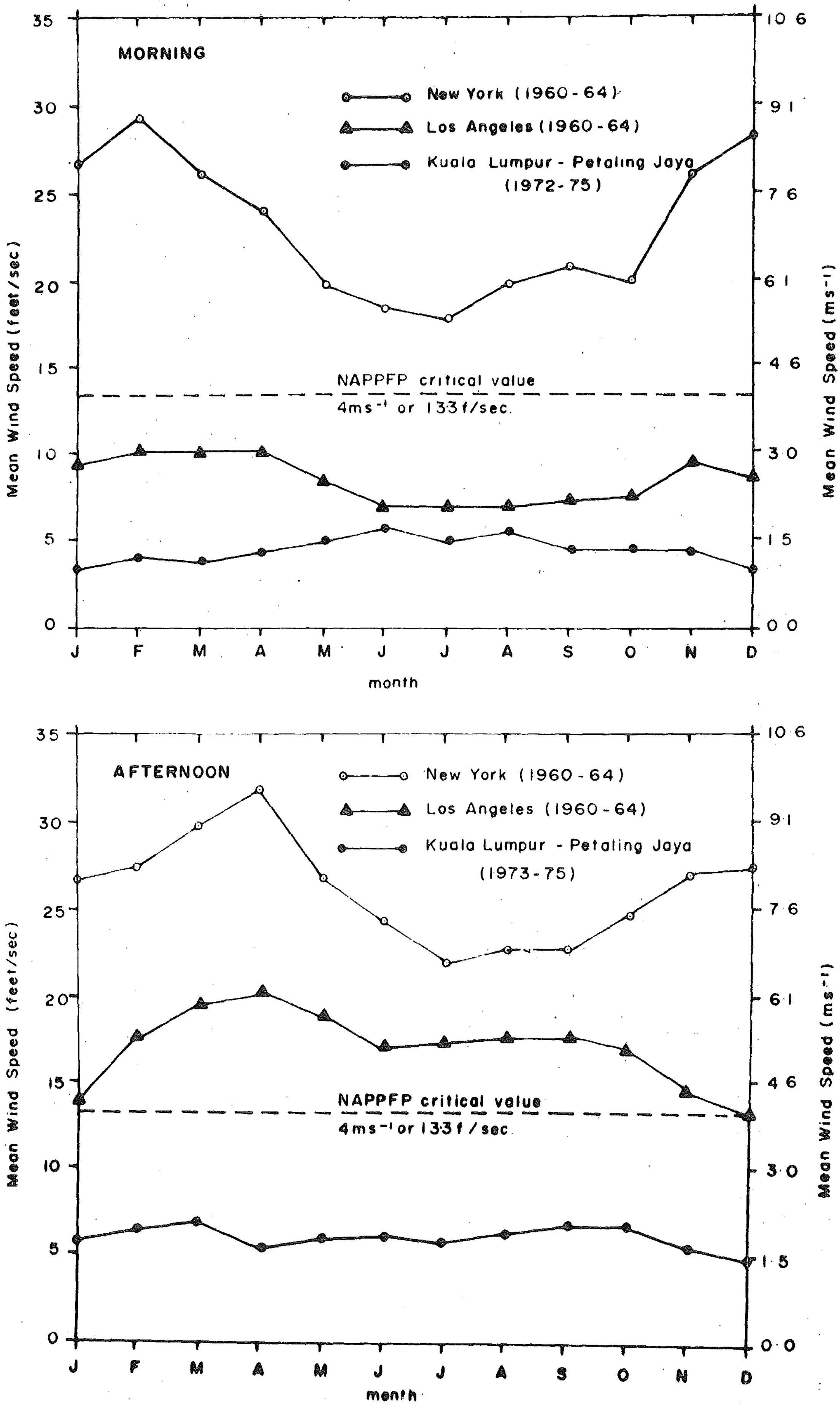


Figure 31: Monthly mean values of the average wind speed through the mixing layer at Kuala Lumpur - Petaling Jaya, Los Angeles and New York

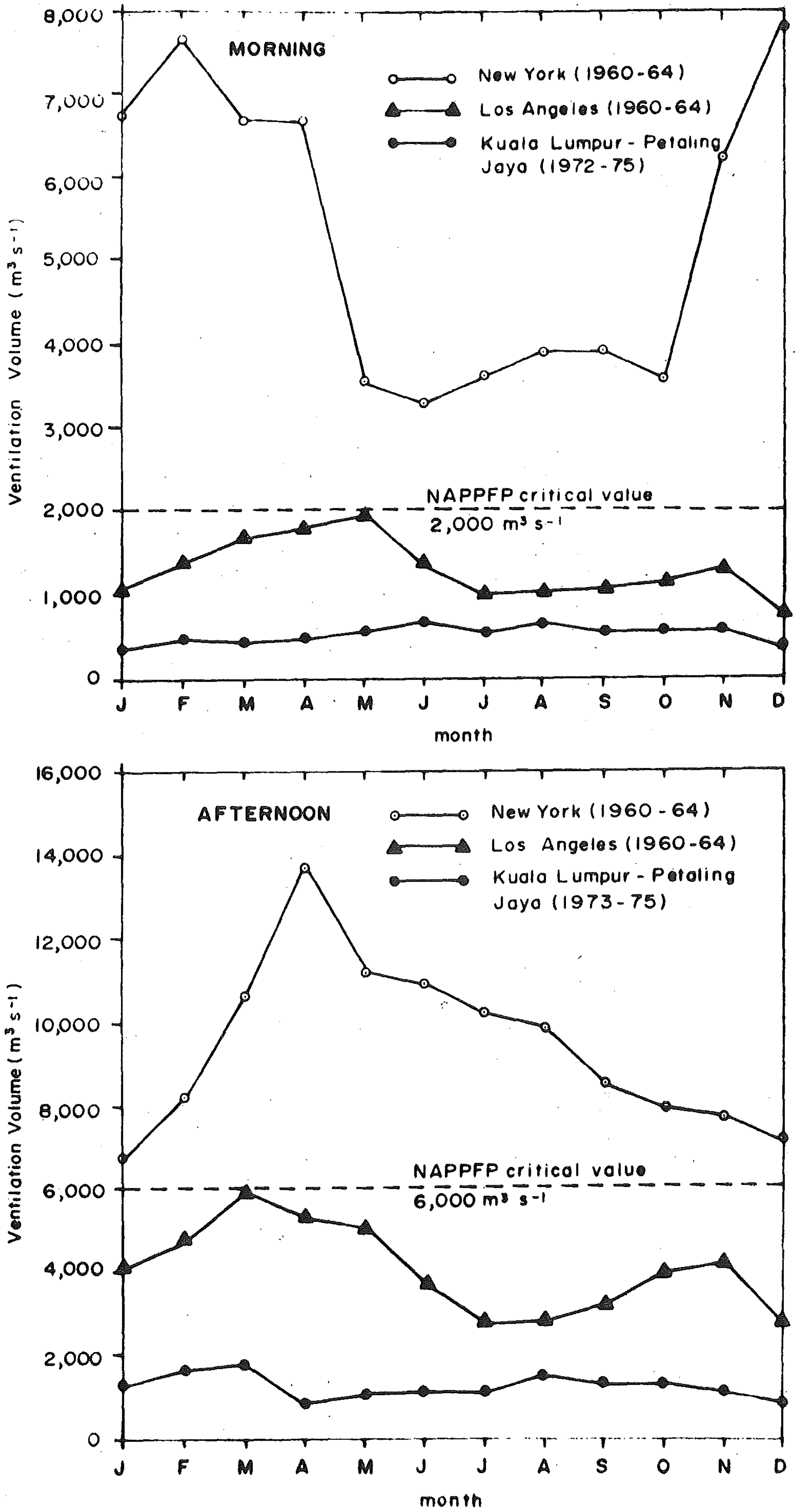


Figure 32: Monthly mean ventilation volumes at Kuala Lumpur - Petaling Jaya, Los Angeles and New York

2.13.2 Radiation and Sunshine and Photochemical Smog

In Chapter 1, two general types of pollution involving primary gaseous pollutants were noted: the 'London' type and the 'Los Angeles' type. It was further noted that the relatively large amounts of nitrogen oxides and various hydrocarbons released by auto-exhausts and other sources coupled with ample sunshine for photochemical reactions provide the essential ingredients for the formation of the Los Angeles type pollution.

In Kuala Lumpur - Petaling Jaya, the near total dependence on the automobiles, the relatively high incidence of stable atmospheric conditions particularly in the morning together with the abundance of sunshine basically complete the necessary set of conditions required for photochemical smog formation. Over the year, Kuala Lumpur - Petaling Jaya receives approximately 2255 hours of sunshine which is nearly 8 percent and 55 percent more than is received over Auckland (Sparrow, 1969) and London (Chandler, 1965) respectively, and is nearly comparable to those of Los Angeles (3200-3300 hours), San Francisco (2800-3000 hours) and New York (2600-2800 hours) (Bryson & Hare, 1974). The annual mean daily solar radiation for Kuala Lumpur - Petaling Jaya is 478.5 langleys/day. This is 68 percent more than that received over London and is comparable to that of Los Angeles (450-500 langleys/day), San Francisco (400 langleys/day) and New York 320-350 langleys/day) (Bennett, 1965). This suggests that photochemical smog formation is possible in Kuala Lumpur - Petaling Jaya. However, studies by overseas groups (Jacobson & Salottolo, 1975) indicate that the meteorological conditions which generally must co-exist for the photochemical smog forming reactions to occur are daily solar radiation greater than 400 langleys, temperatures of $24^{o}C$ or more, relative humidity of 70 percent or less, and an early morning mixing depth less than 1000 metres. This means that although Kuala Lumpur - Petaling Jaya meets most of the requirements, its relative humidity is still somewhat too high in order to satisfy an optimum condition for photochemical. Another factor which may mitigate against its formation is the fact that pollutants are unlikely to be 'trapped' at times of maximum radiation as they often are in Los Angeles by a subsidence inversion aloft combined with topography.

2.13.3 Humidity and 'London' Type Smog Formation

London type of pollution consists mostly of a combination of sulphur oxides and particulates and the following describes one of many possible reactions in this type of pollution. Significant amounts of sulphur dioxide are converted to sulphur trioxide either in combustion processes or through further oxidation in the atmosphere. Sulphur trioxide combines readily with water vapour to form small droplets of sulphuric acid. Here, particulates act as nuclei for the droplet formation. In addition to being corrosive and irritative, sulphuric acid droplets are extremely hygroscopic (Lodge, 1962). The growth of these droplets under high, but still not saturated, humidity conditions produces further reduction in visibility and contributes to the formation of haze and fog. Garnett (1957) reports that these sulphuric acid droplets may become coated with an oily film of pollutants. This film retards evaporation and thus contributes to the persistence of the fog or haze.

The high, but still unsaturated, humidity conditions in Kuala Lumpur - Petaling Jaya has been noted earlier in the previous section; this indicates that the average annual relative humidity is approximately 84 percent with a maximum value of 98 percent. These figures are well above those of London which are 79 and 89 respectively (Chandler, 1965). The much higher temperatures over Kuala Lumpur - Petaling Jaya suggest that the absolute humidity values can be even greater in the study area than they are in London. However, it must be pointed out that most London type fogs have been observed under cold conditions and the degree to which this affects the formation mechanism or merely the volume of emissions has not been established.

2.13.4 Scavenging Effect of Precipitation

A brief discussion on precipitation scavenging has been presented earlier in Chapter 1. The removal of the sub-cloud aerosol by the raindrops as they fall or washout has been noted. Although there is no general agreement on the exact nature of washout processes particularly with regard to very small (less than 1.0µm diameter) pollutant particles, precipitation in the form of rain, drizzle, or snow is the most effective cleanser of the atmosphere (Bach, 1972a). A uniform rainfall of 1.0 mm/hour (0.04 inches/hour) over a 15-minute period can scavenge 28 percent of the 10µm particulates from a volume of air through which the rain passed (Greenfield, 1957).

The abundance of rainfall over Kuala Lumpur - Petaling Jaya has been noted in the previous section. Table 11 indicates that over the year, 55 percent are raindays. In certain months this figure can be even higher. In October, for instance, 77 percent of the days are raindays. This would presumably not allow levels of pollution to build up.

Like the washout process, in-cloud scavenging by the cloud elements and precipitation or rainout is also difficult to assess.

However, if cloud amount is anything to go by, then Kuala Lumpur - Petaling Jaya is certainly in a good position to take full advantage of this.

2.14 Summary

On the basis of both definitions by Fosberg et al (1961) and Thornthwaite (1933), Kuala Lumpur - Petaling Jaya represents a typical tropical city characterized by uniformly high temperatures and heavy annual precipitation well distributed throughout the year.

The climatic variations in Kuala Lumpur - Petaling Jaya are likely to have the following pollution effects: (1) although comparisons between tropical and mid-latitude cities may be prejudiced by the different characteristics of weather conditions and emission properties, standard application of U.S. derived forecasting technique suggests a high pollution potential; (2) following an abundant supply of radiation and sunshine, conditions in the study area appear to be suitable for the formation of photochemical smog. The problem however may not be as serious as that of Los Angeles because pollutants are unlikely to be 'trapped' at times of maximum radiation; and (3) because of high percentage of raindays, scavenging may be significant.

CHAPTER THREE

SOURCES AND SOME ESTIMATES OF AIR POLLUTION EMISSIONS IN THE KUALA LUMPUR - PETALING JAYA AREA

3.1 Introduction

The main aim of this Chapter is to describe some of the major sources of air pollution and arrive at some estimates of pollution emissions in the Kuala Lumpur - Petaling Jaya area based on the patterns of fuel usage. Air pollution from aircraft, open cast tin mines and problems relating to waste disposal are also considered though only qualitative assessments are possible for the last two. In addition, an attempt will be made to assess the types of pollutant which are most prevalent in the study area.

3.2 Major Sources of Pollution

In the Kuala Lumpur - Petaling Jaya area, motor vehicles and industries form the two major pollution sources. Power plants are non-existent within or around the study area, while space heating does not become a problem in the tropics. Air conditioning units and fans which are widely-used cooling systems in the Kuala Lumpur - Petaling Jaya area are run on electricity and do not therefore contribute to air pollution.

3.2.1 Motor Vehicles

Official records of registered motor vehicles for Kuala Lumpur - Petaling Jaya are not available because the Road Transport Department keeps records of registered motor vehicles according to states and not cities or districts. However, the latest returns from traffic counts (October, 1973) conducted by the Transport Planning Unit of the Ministry of Transport indicated that the number of motor vehicles going in and out of Kuala Lumpur - Petaling Jaya was in excess of 360,000 on an average week day. This represents an increase of over 20 percent over the 1972 figure (300,000). The total two-way traffic volumes occurring during the 16 hours from 6.00 a.m. to 10.00 p.m. for the years 1972 and 1973 are shown in Figures 33 and 34 respectively.

In a survey carried out by one of the leading newspapers in the area (Utusan Melayu, 1974) it was estimated that Kuala Lumpur - Petaling Jaya had over 311,000 registered motor vehicles which is more than three times the total number of motor vehicles it had in 1964. In terms of percentage increase over a comparable period, this figure exceeds even those of large North American cities (Table 18).

TABLE 18

Percentage increase in the number of motor vehicles in selected U.S. cities during 1959-69

	% increase
Philadelphia	45.0
New York	39.0
Pittsburgh	39.0
Atlanta	87.0
Los Angeles	30.8
San Francisco	15.8
Seattle	58.8
Denver	19.2
Whole of U.S.A.	38.1

source: Van Tassel, 1973. Our Environment: the Outlook for 1980, Lexington Books, p.311-389.

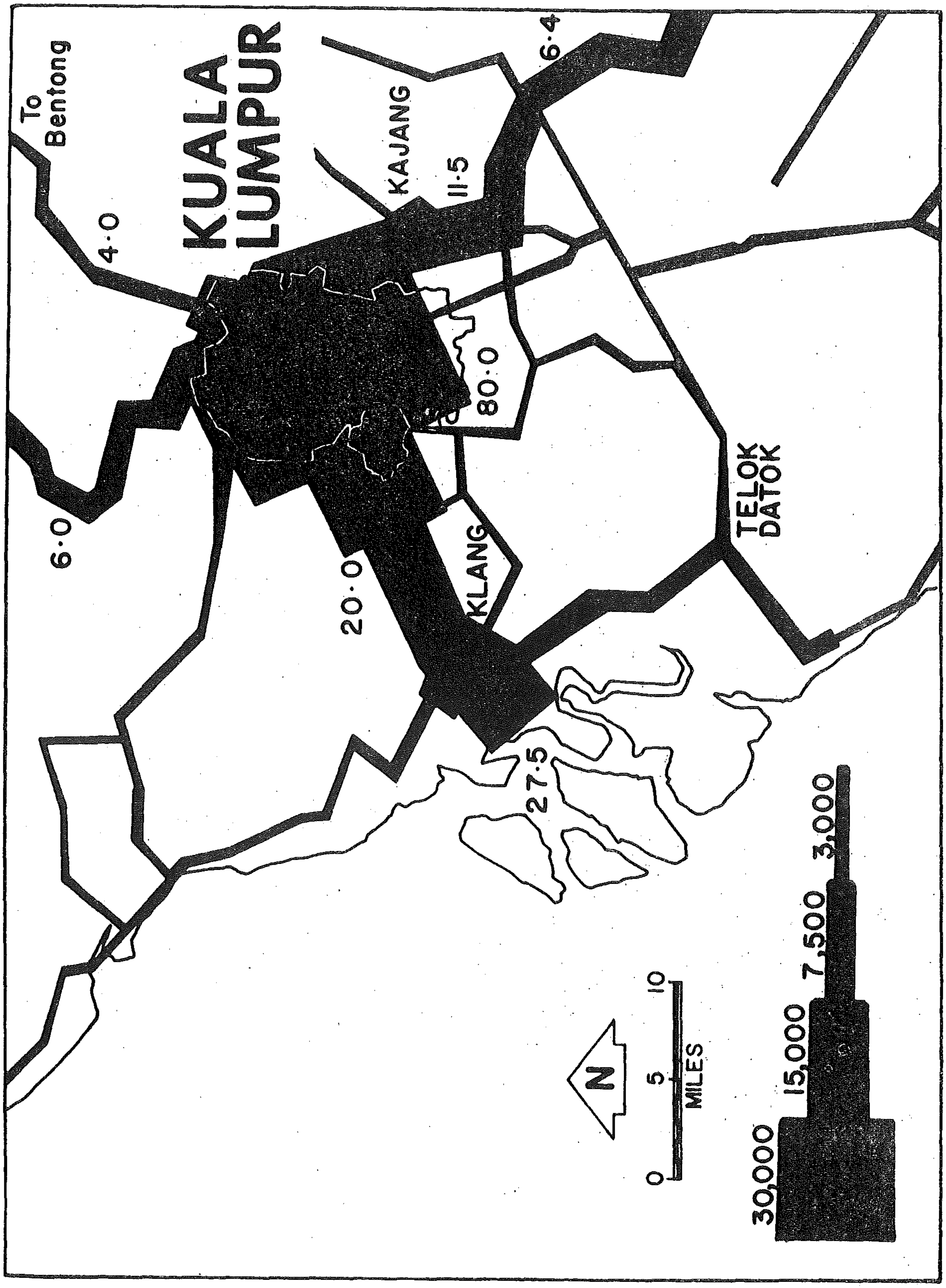


Figure 33: Total 2-way traffic volumes occurring during 16 hours from 6.00 a.m. to 10.00 p.m. as in August, 1972 (source: Unit Perancang Jalan, Malaysia, 1973)

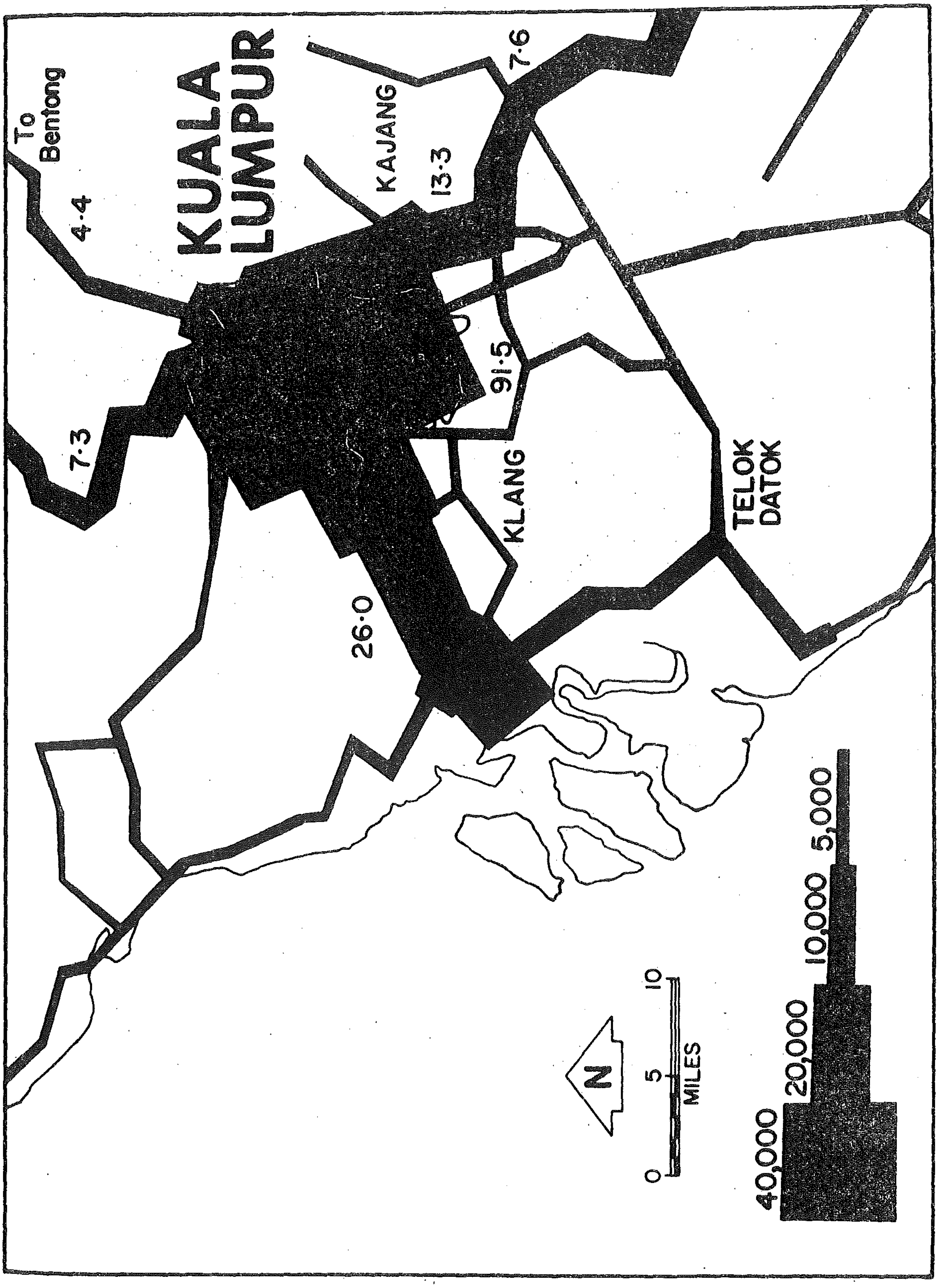


Figure 34: Total 2-way traffic volumes occurring during 16 hours from 6.00 a.m. to 10.00 p.m. as in August, 1973 (source: Unit Perancang Jalan Malaysia, 1974)

The increasing traffic congestion and the ensuing pollution emissions in the Kuala Lumpur - Petaling Jaya urban area are a reflection of both urban growth and increased ownership and utilization of private cars (Plate 2). In 1973, car ownership in Kuala Lumpur was in the region of 33,000 and that of Petaling Jaya, 14,000 (Gun, 1974). In 1975, the car ownership in both Kuala Lumpur and Petaling Jaya increased by over 36 percent reaching a figure in the vicinity of 64,000 (Jones, 1975). About six percent of the households in Kuala Lumpur own two or more cars while 19 percent of those in Petaling Jaya have multiple ownerships.

During an average week-day a total of some 1.025 million person trips were made in and out of the central area of Kuala Lumpur by passenger vehicles (Gun, 1974, p.13). Thirty-five percent were made by buses, 9 percent by taxis and 56 percent by private cars and motor cycles. This unusually high proportion of person trips by private vehicles has increased traffic volumes which exceed the capacities of most of the primary roads within the city, thus resulting in congestion in almost every major junction especially those with round-abouts.

This problem is also attributed to the fact that while the number of vehicles continues to increase within the city, the mileage of roads has remained virtually static. Although attempts have been made by the City authorities to cope with the rising volume of traffic on the roads by means of traffic management schemes, these have had only limited success.

From the point of view of pollutant emission, automobiles are by far the largest source of carbon monoxide and they are also the major source of hydrocarbons and nitrogen oxides, the two types of air pollutants most involved in the formation of photochemical smog.

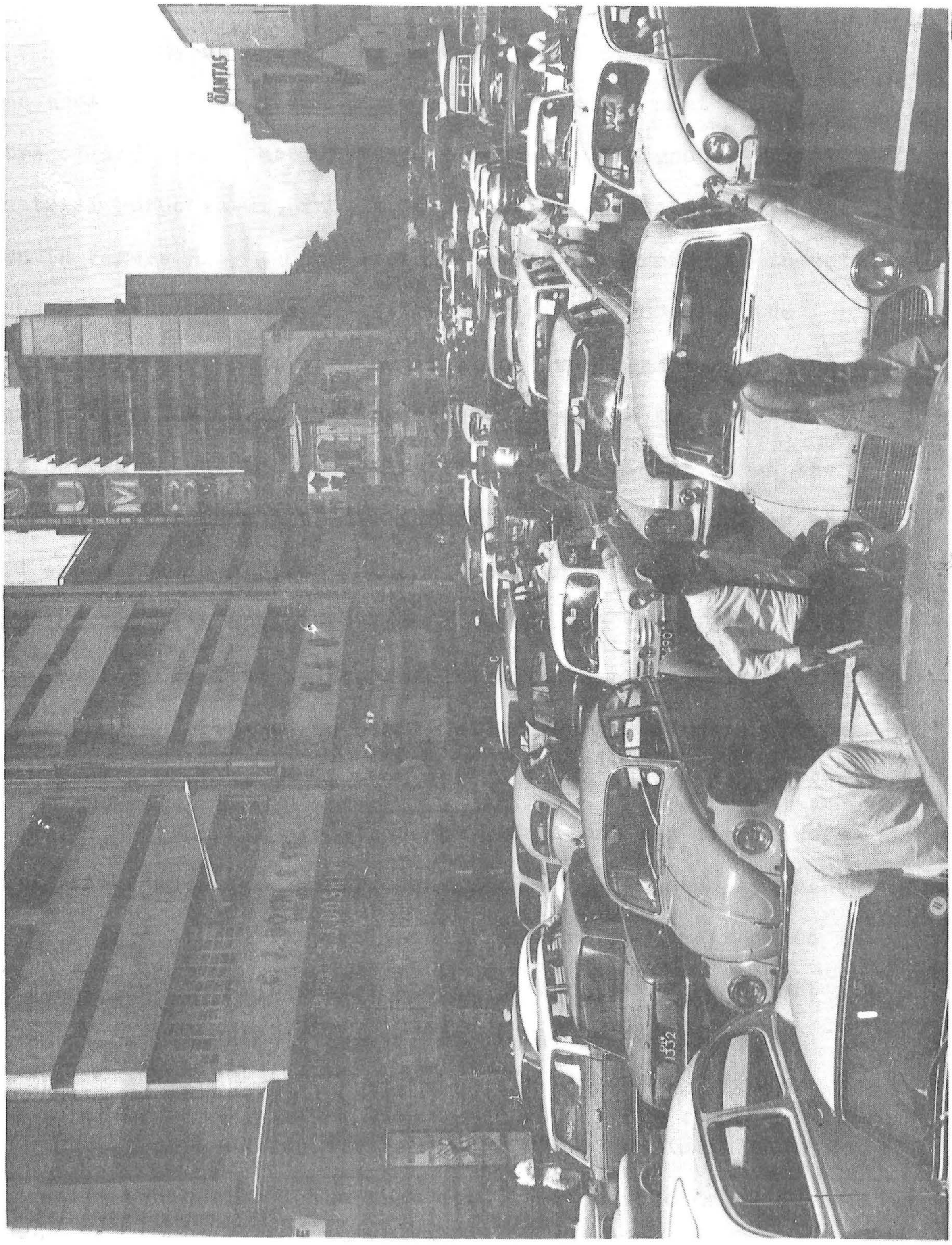


Plate 2: Traffic along a major thoroughfare in Kuala Lumpur central city

3.2.2 Industries

Kuala Lumpur - Petaling Jaya is not only the largest urban area in Malaysia but it is also by far the most important centre of industrial activities. The areas designated for industrial purposes within the Kuala Lumpur - Petaling Jaya area are shown in Figure 5. In the last 10 years, the growth of industries has been very rapid indeed particularly after 1968 when the existing 'Pioneer Industries Legislation' was replaced by a more comprehensive measure, 'The Investment Incentive Act', which modified, extended, and generally tidied up legislation on the subject. Under this Act, new industries achieving pioneer status could expect to be allowed a basic two-year tax-free period of operation but with higher levels of investment this period could become as long as five years, and in certain special cases where an industry was prepared to comply with a number of other government directives, a maximum of eight years tax-free operation could be granted. Payroll tax exemption and investment tax credit were used as incentives for industries which were not actually granted full pioneer status. Export incentives were also introduced in the belief that local industry should be encouraged to export its produce as well as simply serving the local national market (Government of Malaysia, 1969).

Recent data on industries specifically for Kuala Lumpur are not readily available. The last census of manufacturing industries for Peninsular Malaysia was conducted in 1968. Since then only in 1971 was a survey of manufacturing industries again undertaken by the Statistics Department. Table 19 shows that the total number of industrial establishments in Kuala Lumpur - Petaling Jaya represents about 71.8 percent of that of Selangor State as a whole, while in term of workforce, the corresponding figure is 79.2. In the 1971 Survey, it was estimated that both Kuala Lumpur and Petaling Jaya accounted for 81.8 percent of the total establishments and 74.3 percent of the total workforce in Selangor. Figures from both surveys indicate that a large proportion of industrial establishments and their corresponding workforce is heavily concentrated in the Kuala Lumpur - Petaling Jaya area.

TABLE 19

Industrial establishments and work force in Kuala Lumpur-Petaling Jaya, 1968

	No. of establishments	Total Workforce
Kuala Lumpur	1,302	25,547
Petaling Jaya	219	13,879
Selangor State	2,118	49,811

source: Department of Statistics Malaysia, 1969. Census of Manufacturing Industries West Malaysia, 1968, Kuala Lumpur, p.32-36.

In Petaling Jaya, the industrial development in the past 10 years has been even more spectacular. The number of industrial establishments was more than doubled during the 1964-74 period (Table 20). By western standards, however, the industries are mainly small-scale. About 76 percent of the establishments had less than 200 workers (Lim, 1969; Asmah, 1975) with more than 2/3 of the industrial sites having less than one hectare each. The largest industrial site, that of the Dunlop (Malaysia) Sendirian Berhad, extends for about 10 hectares, and is concerned with the manufacture of tyres and tubes.

TABLE 20

Industrial establishments in Petaling Jaya, 1964-74

Year	No. of establishments
1964	130
1965	155
1966	169
1967	190
1968	216
1969	223
1970	245
1971	255
1972	259
1973	264
1974	270

source: Petaling Jaya Town Board

The industries of Petaling Jaya are very diversified in nature. Metal products, electrical goods and transport equipment comprise 30 percent of manufacturing in the area with a relatively strong representation from the chemical products category (18 percent). Food industries and non-metallic products have 14 percent each (Table 21). Altogether, the four industries constituted about 76 percent of the manufacturing industries and employed about 69 percent of the workers.

TABLE 21

Manufacturing Industries in Petaling Jaya

Industries	No. of workers	Percent of firms
Food, beverage, tobacco	1,210	14
Textile, clothing, footwear leather & rubber products	2,016	10
Wood, wood products, furniture	105	2
Paper, printing & publishing	584	6
Chemical and chemical products	1,341	18
Non-metallic products, bricks, glass, cement	1,264	14
Metal products, electrical goods, transport equipments	2,472	30
Others	93	6

(source: Asmah, 1975)

A large majority of industries in Petaling Jaya are light industries. It is estimated that 82 percent of the establishments in Petaling Jaya are 'light' (Asmah, 1975, p.27). Of the remaining 18 percent, a large proportion are metal industries such as the Federal Iron Works, the United Steel Mills, and the Kuala Lumpur Glass, and chemical industries like the Malayan Acid Works and the Malayan Oxygen Limited.

Figure 35 shows some of the major stationary sources of pollution which are causing an increasing amount of concern to

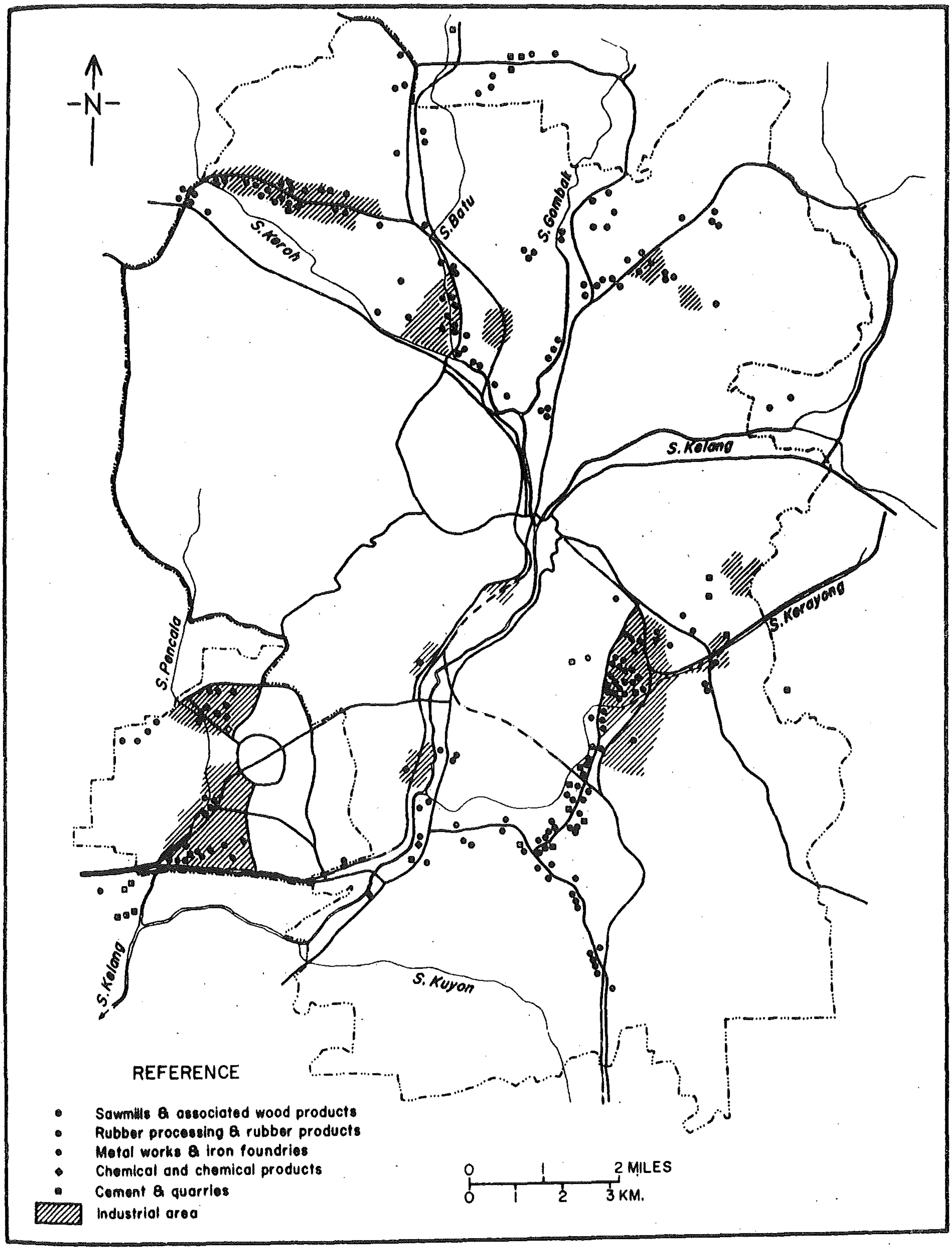


Figure 35: Distribution of major stationary sources of pollution within and around Kuala Lumpur - Petaling Jaya (Field survey)

the general public within and around Kuala Lumpur - Petaling Jaya. These include sawmills, cement works and quarries particularly those in and around Batu Caves to the north of Kuala Lumpur, metal industries and those relating to chemicals and chemical products. Of the latter, the 'rotten-egg' smell from the Malayan Acid Works which is located in Petaling Jaya along the Federal Highway to Kelang appears to be the most objectionable. Rubber processing industries such as the Lee Rubber along Jalan Gombak have also become a source of concern to nearby residents. Most of this type of industries were first operated in places which were once 'isolated' and away from residential areas. However, as development progresses and the demands for homes in the Kuala Lumpur - Petaling Jaya area become more pressing, areas which were once considered isolated have now become centres for housing development. In some cases, factory sites together with the objectionable smell that come from them stand well in the midst of residential areas. The Batu Caves cement works and the Lee Rubber Factory along Jalan Gombak are two cases in point.

To summarize, potentially polluting activities within Kuala Lumpur - Petaling Jaya during the last decade have been experiencing rapid rates of growth. In the case of motor vehicles, these have exceeded even those of large North American cities which, for a long time, have been known for severe pollution from automobiles. Although the growth rates of industrial activities have not been as outstanding as those of automobiles, considered on collective basis, they still form an important source of pollution.

3.3 Fuel Usage in the Kuala Lumpur - Petaling Jaya Area, 1972-75

In this section, an estimate is made of the total amounts of all fuels supplied to the Kuala Lumpur - Petaling Jaya area during the period 1972-75. The relative importance of the different fuels for the many different uses in the study area is considered and in the section that follows an attempt is made to evaluate the probable rates of emission of pollutants from such uses.

Published information relating to the supply and use of fuels within the Kuala Lumpur - Petaling Jaya urban area is almost non-existent. The majority of information used has been supplied entirely by private companies. Without the cooperation of these concerns it would have been impossible to compile a large part of this Chapter. The final figures that are presented must be taken as the best estimates possible based on the data available for fuels used within the Kuala Lumpur - Petaling Jaya urban area.

Table 22 shows the total amount of the various fuels supplied to the Kuala Lumpur - Petaling Jaya area between 1972 and 1975. This indicates that between 1972 and 1975 there was an increase of 39.1 percent in the total fuels estimated to have been used within the area together with 23.1 percent increase in the use of electricity for all purposes. In domestic demand the single most important growth has been for gas, the use of which increased by over 72 percent. Electricity increased by 32 percent. Both increases are the result of urban population growth and the changeover from kerosene to gas as cooking fuel. All major forms of fuel and power consumption for industrial and commercial purposes have also shown increases. This is particularly true of petroleum products the use of which increased by 46 percent. The use of electricity for industrial and commercial purposes increased by 21.6 percent

TABLE 22

Estimate of total fuels supplied to Kuala Lumpur-Petaling Jaya, 1972-75, in thousands of tons and electricity in million of units

	1972	1973	1974	1975
Domestic				
Kerosene	50.1	50.1	52.2	53.6
Gas	14.3	19.3	22.6	24.7
	64.4	69.4	74.8	78.3
Industrial and Commercial				
Gas	3.1	3.5	3.7	3.7
Petroleum products - fuel & gas oils	229.4	260.8	315.1	334.8
	232.5	264.3	318.8	338.5
Transport				
Motor spirits	146.4	172.1	192.3	211.3
Gas oils	111.2	100.1	134.7	143.0
	257.6	272.2	327.0	354.3
TOTAL TONS (THOUSANDS)	554.5	605.9	720.6	771.1
Electricity				
Domestic	165.1	183.7	201.2	217.9
Industrial & Commercial	923.2	976.4	1,073.1	1,122.3
Transport	12.6	13.6	14.3	14.6
TOTAL UNITS (MILLIONS)	1,100.9	1,173.7	1,288.6	1,354.8

source: Malaysian oil companies and the National Electricity Board, Malaysia.

and gas by 19.4 percent. With regard to transport, petroleum products are by far the most significant fuels. The use of coal by the railways ceased during 1963 and today all railway engines are diesel operated. Motor spirits shows the greatest increase with 44.3 percent while the increase for gas oils is 28.6 percent.

Table 23 illustrates the data in Table 22 for 1972 and 1975 converted to kilowatt hours thus making the information on fuel supplied to Kuala Lumpur - Petaling Jaya comparable on an energy equivalent basis. These show that over the 1972-75 period there has been a 34.7 percent increase of total energy supply. Gas oils dominate the scene accounting for 31.6 percent of the total in 1975 although this is 3.4 percent less than the corresponding figure in 1972. This is followed by motor spirits and fuel oils both of which indicate positive changes over the 1972 figures in terms of percentage of annual total. Altogether, petroleum products accounted for over 87 percent of the total energy supply during 1975; the remainder comes from electricity.

3.3.1 Oil

With the exception of kerosene, there has been a marked increase in the amount of all petroleum products supplied to Kuala Lumpur - Petaling Jaya over the 1972-75 period (Table 24). This reflects a general trend which is occurring throughout the country as a result of a number of factors among which are the increasing number of motor vehicles on the roads and the growth of new industries (see sections 3.2.1 and 3.2.2). Kerosene which is used mainly for cooking and in some cases lighting purposes, however, has shown only slight increase (3.3 percent) over the 1972-75 period. This reflects its declining importance as fuel for

TABLE 23

Energy supplied to the Kuala Lumpur-Petaling Jaya area, 1972-75 (in million of KWhr.) and as a percentage of annual total

Energy source	1972	% of annual total	1975	% of annual total	Change in percentage 1972-75
Motor spirits	1,940.53	25.03	2,801.61	26.82	+1.79
Gas oils	2,711.12	34.97	3,300.70	31.60	-3.37
Fuel oils	1,305.46	16.84	2,269.45	21.72	+4.88
Kerosene	694.90	8.96	718.18	6.87	-2.09
Gas	0.15	*	0.24	*	*
Electricity	1,100.96	14.20	1,356.73	12.99	-1.21
Total	7,753.12	100.00	10,446.91	100.00	-

* Negligible
source: Malaysian oil companies, Malaysian gas companies, and Malaysian Electricity Board

Footnote:

Figures in this Table were derived by converting those in Table 22 to kilowatt hours using the following conservative calorific values for the different fuels:

Fuel	Calorific Value	
Motor spirits	20,200	Btu's per pound
Gas oils	19,500	Btu's " "
Fuel oils	18,500	Btu's " "
Kerosene	19,900	Btu's " "
Gas	450	Btu's per cubic foot
Electricity	1,000,000	Btu's per 293 KWhr.

cooking in the face of strong competition from gas over the last five years.

TABLE 24

Petroleum products supplied to the Kuala Lumpur - Petaling Jaya area, 1972-75 (tons)

	1972	1973	1974	1975	% increase 1972-75
Motor spirits	146,370	172,094	192,310	211,320	44.4
Gas oils	211,835	212,719	257,640	257,903	21.8
Fuel oils	125,719	144,959	190,562	218,554	73.8
Kerosene	53,205	53,255	53,682	54,980	3.3
Total	537,129	583,027	694,194	742,757	38.3

source: Malaysian oil companies

The combustion and handling of petroleum products can result in a number of air pollutants which include hydrocarbons and other organic gases, nitrogen oxides and sulphur dioxide. The amount of sluphur dioxide emitted from burning petroleum products depends on their sulphur content. The sulphur content of motor spirits is normally less than 0.05 percent by weight while that of gas oil is less than 0.47 percent. Of considerable significance to air pollution are the fuel oils which have a sulphur content varying normally from 1.0 percent to 2.9 percent by weight although the maximum may be as high as 3.5 percent (Sparrow, 1969). This is significant to Kuala Lumpur - Petaling Jaya particulary in the light of a near 74 percent increase in fuel oils over the 1972-75 period.

Detailed information about the use of petroleum products within Kuala Lumpur - Petaling Jaya was unfortunately not available from oil companies and consequently the distribution of major oil users cannot be plotted although it is likely to be in the industrial areas and within the central business district.

3.3.2 Electricity

The first public supply of electricity to Kuala Lumpur was in 1905. This came from a small hydroelectric station at the 12th Mile Pahang Road in Ulu Gombak (Appendix I). Private demand expanded rapidly and by 1919, the Ulu Gombak Station was inadequate. Another station (with mixed generating plant totalling 1450 kW) was established at Gombak Lane which was later transferred to a site at Bangsar in 1926. This was subsequently closed down in 1963 and supply for the area was obtained from the Connaught Bridge Power Station (80 MW) and Ulu Langat Hydro Station (2.3 MW) both of which were well away from the Kuala Lumpur - Petaling Jaya area.

By 1972, the National Grid covered practically the whole of the west coast from Kangar in Perlis in the north to Johore Bharu in the south (Figure 36). It has also been extended across the Main Range to Bentong and Mentakab. Plans are in hand to extend the National Grid to Kuantan, Pekan, Lumut, Bukit Ketri in Perlis and Pasir Gudang in Johore. A 275 KV Supergrid will eventually be superimposed onto the existing 132 KV Grid. The Kuala Lumpur - Port Dickson Power Station link is already operating at 275 KV. Parts of this Supergrid link between Kuala Lumpur and Papan are now being constructed. Temenggor Hydro Station will be connected to the Grid at Papan at 275 KV when it is completed in 1977.

It can be observed therefore that Kuala Lumpur - Petaling

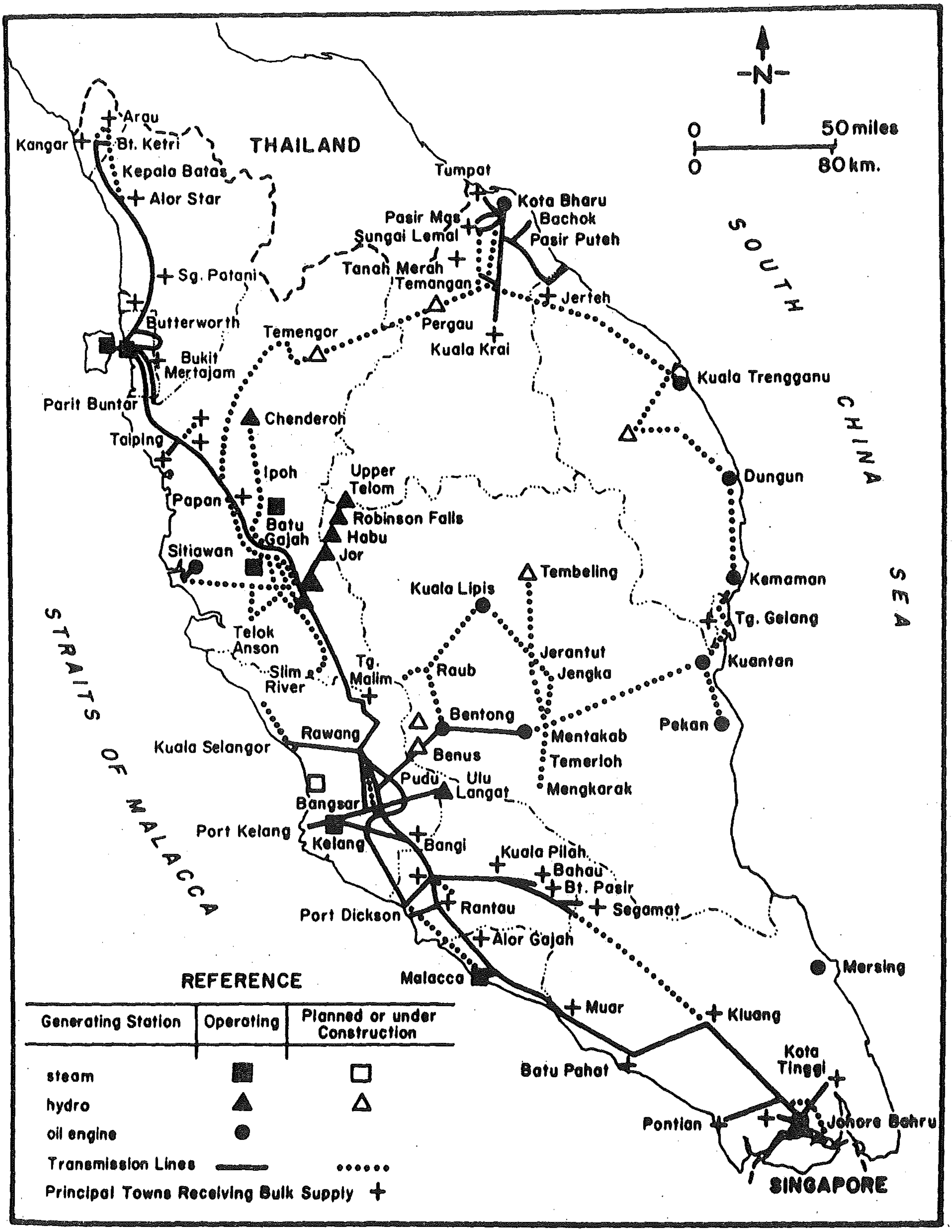


Figure 36: Principal generating stations and transmission lines, 1972-75 (Malaysian National Electricity Board, undated)

Jaya is in many ways, fortunate in that the sources of its electrical energy have been largely well away from the built-up area particularly after the closing down of the Bangsar Power Station in 1963. If electricity is produced far outside an urban centre and transported to the area of demand, contamination of the urban area's atmosphere by its generation is unlikely. If, however, the power is generated within the urban area the situation can be decidedly different when the fuels are coal or oil.

Table 25 shows the amounts of electricity supplied to Kuala Lumpur - Petaling Jaya during the 1972-75 period together with the percentage increase of the different uses of electricity during the four years. The largest increase for domestic purposes (32 percent) reflects the rapid growth of population in the Kuala Lumpur - Petaling Jaya area.

TABLE 25

Electricity supplied to the Kuala Lumpur-Petaling Jaya area, 1972-75 (thousands of units)

	1972	1973	1974	1975	% increase 1972-75
Domestic	165,096	183,689	201,167	217,913	32.0
Industrial & Commercial	923,218	976,418	1,073,086	1,122,268	21.6
Transport	12,645	13,624	14,337	14,548	15.1
Total	1,100,959	1,173,731	1,288,590	1,354,729	23.1

source: National Electricity Board, Malaysia

3.3.3 Gas

Gas is largely used for domestic purposes and has experienced a dramatic increase of over 72 percent over the 1972-75 period (Table 26). The corresponding increase for industrial and commercial purposes has been less than 17 percent. Gas has replaced kerosene as a source of fuel for cooking and its importance is likely to continue particularly following the present trend of population growth within and around Kuala Lumpur - Petaling Jaya.

TABLE 26

Gas supplied to the Kuala Lumpur-Petaling Jaya area, 1972-75 (thousands of cubic feet)

	1972	1973	1974	1975	% increase 1972-75
Domestic	909.7	1,224.3	1,438.3	1,568.0	72.4
Industrial & Commercial	194.0	220.1	232.3	226.5	16.8
Total	1,103.7	1,444.4	1,670.6	1,794.5	62.6

source: Malaysian gas companies

To summarize, marked increases in energy use have occurred over the 1972-75 period. The major parts of these have taken place in motor spirits and fuel oils. In terms of percentage of annual total, petroleum products account for over 87 percent of the total energy supply during 1975; the remainder comes from electricity. Although the present energy crisis may slow down slightly the rate of increase of energy use within the study area, both the general patterns and trend are not expected to change greatly in the forseeable future. The implications of these for pollution levels are considerable particularly following large increases in nitrogen oxide, hydrocarbon and sulphur dioxide emissions as a result of incomplete combustion of fuel oils. This coupled with climate which is characteristically high in pollution potential, is certainly a cause for concern.

3.4 Estimate of Emission of Pollutants from Fuels Supplied to Kuala Lumpur - Petaling Jaya, 1972-75

In the assessment of community air pollution, there is a critical need for accurate data on the quantity and characteristics of emissions from the numerous sources that contribute to the problem. The large numbers of these individual sources and the density of source types make conducting field measurements of emissions on a source-by-source basis at the point of release impractical. The only possible method of determining pollutant emissions for a given community is to make generalized estimates of typical emissions from each of the source type.

Emission inventory data have many applications in air conservation programmes. They can be used effectively in metropolitan planning, pollution abatement, initiation of samplings, interpretation of sampling results, and estimation of anticipated pollutant concentrations in the atmosphere. A detailed account of these is described in Ozolins & Smith (1968) and the U.S. Environmental Protection Agency (1972).

From the estimates of total fuels supplied to Kuala Lumpur - Petaling Jaya over the 1972-75 period and by using emission factors for the main pollutants resulting from the use of fuels an attempt was made to calculate the total estimated annual emissions for 1972 and 1975. These are given in Table 27 which has been produced using the fuels supplied to the study area in 1972 and 1975 and emission factors mainly from, or based on, those given by Ozolins & Smith (1968) and Duprey (1968). Pollutants considered are carbon monoxide, hydrocarbons, oxides of nitrogen, oxides of sulphur, and particulates.

In 1975, approximately 82,600 tons of carbon monoxide, 17,700 tons of hydrocarbons, 10,000 tons of oxides of nitrogen, 6,600 tons of oxides of sulphur and 2,650 tons of particulate materials were produced from the combustion of fuels. The bulk of carbon monoxide and hydrocarbons comes from motor spirits accounting respectively for 98.7 and 83.7 percent of the total. The main source of oxides of nitrogen is gas oils followed by motor spirits as a close second. Both gas oils and motor spirits account for over 77.0 percent of the year's total of oxides of nitrogen. Oxides of sulphur is produced mainly by gas oils and fuel oils accounting for nearly 96.0 percent of the total. About 73.0 percent of the particulate materials come from gas oils.

Between 1972 and 1975 there was an increase in pollution emitted from all sources. Fuel oils recorded the largest increase with nearly 74.0 percent followed by motor spirits with 44.4 percent. Air pollution emitted from gas oils and kerosene increased by 24.7 and 7.0 percent respectively. It is worth noting that although the absolute amount of air pollution produced by gas was very small, this represents an increase of 65.8 percent over the 1972 figure.

Table 28 shows the major sources of air pollutant emissions in Kuala Lumpur - Petaling Jaya as estimated from the supply of fuels during 1975. Transport accounts for nearly 92.0 percent of total emissions and together with industries they produce over 99.0

TABLE 27

Estimated Emissions from Fuels Supplied to the Kuala Lumpur-Petaling Jaya Area, (a) 1972 and (b) 1975

		Pollutants Discharged (tons)							
		Fuel burned ('000 tons)	Carbon monoxide	Hydrocarbon	Oxides of nitrogen	Oxides of sulphur	Particulates	Total pollutants	% of total
(a)	Motor spirits	146.4	56,474.8	10,169.3	2,193.0	174.7	213.4	69,225.2	82.7
	Gas oils	211.8	776.5	2,284.0	3,607.1	2,309.3	1,518.3	10,495.2	12.5
	Fuel oils	125.7	26.0	26.0	937.5	2,070.3	156.3	3,216.1	3.8
	Kerosene	53.2	N.A.	19.3	594.0	25.7	121.9	760.9	1.0
	Total*	537.1	57,277.3	12,498.6	7,331.6	4,580.0	2,009.9	83,697.4	100.0
	Gas	1.1m.cu.ft.	0.4 gm.	-	128.0 gm.	0.4 gm.	18.2 gm.	147.0 gm.	-

		Pollutants Discharged (tons)							
		Fuel burned ('000 tons)	Carbon monoxide	Hydrocarbon	Oxides of nitrogen	Oxides of sulphur	Particulates	Total pollutants	% of total
(b)	Motor spirits	211.3	81,534.6	14,681.8	3,166.1	252.2	308.2	99,942.9	83.7
	Gas oils	257.9	995.2	2,933.5	4,520.2	2,709.4	1,931.5	13,089.8	10.9
	Fuel oils	218.6	45.3	45.3	1,629.8	3,599.2	271.6	5,591.2	4.7
	Kerosene	55.0	N.A.	20.6	635.8	27.5	130.5	814.4	0.7
	Total*	742.8	82,575.1	17,681.2	9,951.9	6,588.3	2,641.8	119,438.3	100.0
	Gas	1.8m.cu.ft.	0.7 gm.	-	208.2 gm.	0.7 gm.	34.1 gm.	243.7 gm.	-

* Pollutants discharged from gas excluded   N.A. not available

TABLE 28

Major Sources of Air Pollutant Emissions in the Kuala Lumpur-Petaling Jaya area (tons), 1975, as estimated from supply of fuels*

Source	Carbon Monoxide	Hydrocarbons	Oxides of nitrogen	Oxides of sulphur	Particulates	Total	% of total
Transport	82,504.8	17,599.3	6,752.0	898.3	2,085.0	109,839.4	91.9
Industry	71.3	71.3	2,564.1	5,698.5	427.3	8,832.5	7.4
Domestic	-	20.6	635.8	27.5	130.5	814.4	0.7
Total	82,576.1	17,691.2	9,951.9	6,624.3	2,642.8	119,486.3	100.0

* Pollutants discharged from gas excluded

percent of the pollutants emitted in the study area. Compared with the situation in 1972 (Table 29), the position of transport as the major source of air pollution is unchanged. Air pollution from industries showed an increase of 0.2 percent while that from domestic sources indicated a decline of 0.2 percent. The decline from domestic sources have been due largely to the switch from kerosene to gas as cooking fuel.

The role played by motor vehicles as the major source of air pollution in the Kuala Lumpur - Petaling Jaya area surpasses even that of the United States (Table 30) where substantial amount of air pollution is also contributed by industry, power plants and space heating. In Kuala Lumpur - Petaling Jaya particularly and indeed in most tropical cities generally, domestic space heating is non-existent. Air conditioning units and fans which are widely-used cooling systems are normally run on electricity and do not therefore contribute to air pollution directly especially in cases where electricity is produced far outside the urban centres. Industries are also mainly light in nature and do not produce as much air pollution. However, in the study area, there is a tendency for an increase of air pollutant emission during the 1972-75 period from industries. Although the role of industries as one of the major sources of air pollution is likely to increase following emphases given to this sector in the Third Malaysia Plan, it is not expected to supercede transport as the major source of pollution in the study area.

Attempts to compare Kuala Lumpur - Petaling Jaya emissions with those of other cities are not always easy. The emission factors used, the types of sources and pollutants considered in each case may sometimes be quite different such that indiscriminate

TABLE 29

Major Sources of Air Pollutant Emissions in the Kuala Lumpur-Petaling Jaya area (tons), 1972 as estimated from supply of fuels*

Source	Carbon monoxide	Hydrocarbons	Oxides of nitrogen	Oxides of sulphur	Particulates	Total	% of total
Transport	57,228.6	12,430.6	4,981.9	677.2	1,595.3	76,913.6	91.9
Industry	48.7	48.7	1,755.7	3,877.1	292.7	6,022.9	7.2
Domestic	-	19.3	594.0	25.7	121.9	760.9	0.9
Total	57,277.3	12,498.6	7,331.6	4,580.0	2,009.9	83,697.4	100.0

* Pollutants discharged from gas excluded

TABLE 30

Major Sources of Air Pollutant Emissions in the United States
(million of tons/year)

Source	Carbon monoxide	Hydrocarbon	Oxides of nitrogen	Oxides of sulphur	Particulates	Total pollutants	% of total
Motor vehicles	66	12	6	1	1	86	60
Industry	2	4	2	9	6	23	17
Power plants	1	1	3	12	3	20	14
Space heating	2	1	1	3	1	8	6
Refuse disposal	1	1	1	1	1	5	3
Total	72	19	13	26	12	142	100

Source: USDHEW, 1966. The Sources of Air Pollution and Their Control, PHS Publication No.1548, Washington, D.C.

comparison may be misleading. In Table 31 figures for U.S. cities have been expressed as percentage of total emissions from automobiles, power plants and heating only, while those for Christchurch, Auckland, and Kuala Lumpur - Petaling Jaya, on the other hand, refer to percentage of total. These have made comparisons difficult. However, in the absence of availability of a more readily comparable data, Table 31 does give an idea of the relative contribution of major emission sources in the different cities. This generally suggests that the situation in Kuala Lumpur - Petaling Jaya in term of emission sources is much similar to those of Los Angeles, San Francisco and Salt Lake City where over 90.0 percent of the total air pollutant emissions come from automobiles. It may be added that although industries have been excluded in the calculation of total emissions for U.S. cities in Table 31, the conclusions reached are not expected to be greatly different particularly in the case of Los Angeles where emissions from industries are relatively negligible (Fennimore, 1973).

In terms of actual absolute amounts of emissions, some form of comparison with other cities are provided by Table 32 where average concentrations of pollutant emissions have been expressed both in (a) tonnes/km^2/year, and (b) $\mu g/m^3$. To obtain figures for (b), a modified concept of the simple box model as described in Masters (1974, p.222) was assumed where pollutant emission rate was divided by the product of the city area and the mean maximum mixing depth. Information on wind speed and direction, and the base dimension of each city in the prevailing wind direction were not available and were therefore excluded in the calculation of pollution concentration. Mixing depth was estimated from maps prepared by Holzworth (1964 & 1967) for American cities, while that

TABLE 31

Sources of Air Pollution[a] from Selected Cities expressed as percentage of total. For U.S. cities, these are expressed as percentage of total emission from automobiles, power plants and heating only

	Percent of total		
	Automobiles	Power Plants	Heating[b]
New York (1969)	69.4	12.3	18.3
Pittsburgh (1969)	71.1	23.1	5.8
Atlanta (1969)	55.0	38.1	6.9
Los Angeles (1969)	98.6	1.4	Negligible
San Francisco (1969)	97.1	2.3	0.6
Salt Lake City (1969)	94.2	5.1	0.7
Christchurch (1973)*	51.3	-	13.5[c]
Auckland (1966)*	76.5	-	2.4
Kuala Lumpur-Petaling Jaya (1975)*	91.9	-	-

(a) Air pollutants considered are carbon monoxide, hydrocarbons, oxides of nitrogen, oxides of sulphur, and particulates.

(b) Includes commercial and industrial.

(c) Applies only to domestic heating.

* Industry and commerce contribute 35.2 percent of total emissions in Christchurch, 21.1 percent in Auckland, and 7.4 percent in Kuala Lumpur-Petaling Jaya. In Kuala Lumpur-Petaling Jaya, 0.7 percent is attributable to domestic cooking.

(Source: Van Tassel, 1973; Kennedy *et al*, 1974; Sparrow, 1969)

TABLE 32

Average Concentration of Pollutant Emissions for Selected Cities expressed in (a) tonnes/km^2/year, and (b) $\mu g/m^3$. In the latter, figures were derived by dividing total daily emissions for each city by the product of its area and mean mixing depth

		Carbon monoxide	Hydrocarbons	Oxides of nitrogen	Oxides of sulphur	Particulates	Total
New York SMSA (1969)	a	588.92	154.23	131.17	577.98	23.45	1475.75
	b	1337.54	350.27	297.92	1312.70	53.25	3351.68
Pittsburgh SMSA (1969)	a	82.81	21.75	15.96	34.09	6.51	161.12
	b	161.85	42.50	31.20	66.63	12.73	314.91
Atlanta SMSA (1969)	a	37.01	12.24	10.58	30.22	7.56	97.61
	b	94.44	31.23	26.98	77.10	19.30	249.05
Chicago City (1969)	a	2324.93	1531.90	555.39	1412.13	273.32	5163.21
	b	1913.01	7444.47	1778.37	4521.66	875.16	16532.67
St. Louis City (1969)	a	2823.04	751.96	650.00	1701.47	337.74	6264.21
	b	2501.60	9391.60	2162.40	5660.40	1123.60	20839.60
Cleveland City (1969)	a	2707.91	693.68	590.91	1243.48	277.47	5513.45
	b	2311.20	9022.24	1968.80	4143.04	924.48	18369.76
New Orleans City (1969)	a	381.89	96.96	81.13	1.98	3.96	565.92
	b	290.57	1144.49	243.13	5.93	11.86	1695.98
Los Angeles City (1969)	a	2397.03	630.80	253.16	22.71	1.68	3305.38
	b	8350.50	2197.50	881.93	79.11	5.86	11514.90
San Francisco City (1969)	a	1778.19	558.37	283.48	Negligible	8.59	2628.63
	b	7025.58	2206.10	1120.02	Negligible	33.94	10385.64
Salt Lake City (1969)	a	1019.40	256.50	144.69	72.35	6.58	1499.52
	b	1280.30	322.14	181.72	90.86	8.26	1883.28
London (1957)	a	682.50*	284.70	284.70	697.52†	313.17	2262.59*
	b	-	-	-	-	-	-
Auckland (1966)	a	122.85*	19.63	21.50	23.25†	8.28	195.51*
	b	-	-	-	-	-	-
Christchurch (1973)	a	185.25*	73.87	36.16	37.49†	22.33	355.10*
	b	576.51*	229.90	112.54	116.70†	69.51	1105.16*
Kuala Lumpur-Petaling Jaya (1975)	a	315.73	67.64	38.05	25.33	10.11	456.86
	b	1271.67	272.44	153.26	102.01	40.70	1840.08

* estimated

† Figures refer to SO_2 only

(source: Van Tassel, 1973; Sparrow, 1969; Kennedy *et al*, 1974; Christchurch Regional Planning Authority, 1972; Holzworth, 1964 & 1967; Tapper, 1976) for Christchurch, New Zealand was derived from Tapper (1976). Sources for other variables are noted at the bottom of the Table.

Results in Table 32 suggest that although emissions for Kuala Lumpur - Petaling Jaya are still small by western standards, these have nearly equalled those of some city areas in the United States. The emissions would have probably been greater if only the central business district of Kuala Lumpur had been considered and that wind speed through the mixing depth was included as a variable in the calculation of pollution concentration. The inclusion of wind speed in the calculation would result in the relative increase of concentration values for Kuala Lumpur - Petaling Jaya by a factor of several times when compared, for example, with those of New York and Los Angeles (see Chapter 2) as wind speeds in the study area are a great deal lower than those experienced in most mid-latitude cities.

The average concentration of pollutant emissions by weight and expressed as percentage of total for selected cities (Table 33) suggests that Kuala Lumpur - Petaling Jaya is subject to the 'Los Angeles' type pollution with a high percentage of carbon monoxide. This is expected as nearly 92 percent of the total pollutant emissions in the area comes from automobiles (Tables 29 and 31).

3.5 Estimates of Air Pollutant Emissions from Aircraft

Aircraft operating on and around airports are known to contribute to the levels of air pollution recorded. It has been established that the aviation industry contributes to about 1.0 percent of total world pollution from energy consumption (Bourke, 1973). Although this may not seem significant on a global scale, its impact on the local environment could be far-reaching. A

TABLE 33

Average Concentration of Pollutant Emissions by Weight for Selected Cities Expressed as Percentage of Total†

	Carbon monoxide	Hydrocarbon	Oxides of nitrogen	Oxides of sulphur	Particulates
Los Angeles (1969)	72.5	19.0	7.7	0.7	0.1
London (1957)	30.2	12.6	12.6	30.8*	13.8
New York (1969)	39.9	10.4	8.9	39.2	1.6
Christchurch (1973)	52.2	20.8	10.2	10.5*	6.3
Auckland (1966)	62.8	10.0	11.0	11.9*	4.3
Kuala Lumpur-Petaling Jaya (1975)	69.1	14.8	8.3	5.6	2.2

† For Los Angeles and New York, total weight refers only to emission from automobiles, power plants and heating.

* Figures refer to SO_2 only.

(source: Calculated from Table 32)

study of the impact on the air environment of jet aircraft operations at the Los Angeles International Airport indicates that aircraft contributes about 91.0 percent of the particulates and 44.0 percent of the carbon monoxide emissions (George et al, 1972). Carbon monoxide emissions from ground operations were found to be more than 55.0 percent of the total carbon monoxide emissions from all sources.

Close to Kuala Lumpur - Petaling Jaya, there are a number of potential sources of atmospheric pollution by aircraft. These are the Subang International Airport, the Royal Malaysian Air Force base at Salak South, and the aerodrome at Segambut (Appendix I). The International Airport at Subang is about 16km (10 miles) from Kuala Lumpur Central City and is the busiest in the country. The Airport was opened during 1966. Before this, international and domestic scheduled flights were operated from the present Royal Malaysian Air Force base at Salak South.

For reasons of security, details of flights and aircraft types are not available from the Royal Malaysian Air Force station at Salak South during the 1972-75 period. The aerodrome at Segambut has been operating only recently and the number of aircraft operating from here is small. It is used solely to carry passengers to the Genting Highlands, a holiday resort some 32km (20 miles) to the northeast of Kuala Lumpur. Because of the relatively small number of flights operating from these two bases (about 9 flights/day from Segambut), it is felt that their exclusion from the calculation of air pollutant emissions from aircraft will not greatly affect the result. Details about the mode of power and the number of flights recorded at the Subang International Airport over the

1972-75 period are shown in Table 34. The Table shows that flights by jet aircraft have now reached significant proportion; the 1975 annual statistics indicate that these are 72.6 percent of total flights compared to 61.4 percent in 1972. Flights by piston driven aircraft on the other hand, have shown a substantial decline over the period while those by turbo-propeller driven aircraft have maintained much the same figure (in term of percent of total) for the last three years. Carbon monoxide is the major constituent of the pollutants particularly from piston driven aircraft, and will decrease as flights by this type of aircraft decline in number. The emissions of oxides of nitrogen, particulate matter and hydrocarbons will all increase in the future as more flights by jet and turbo-propeller driven aircraft occur.

From the number of flights and types of aircraft used, and by using emission factors for the main pollutants resulting from such flights, an attempt was made to calculate the total estimated emissions for the 1972-75 period. These are given in Table 35 which has been produced using the emission factors suggested by Ozolins & Smith (1968) and George <u>et al</u> (1972). These factors are combined and averaged figures for emissions during all phases of aircraft operations (taxi, takeoff, climbout, approach, and landing) that take place below that arbitrarily chosen altitude of 1,060.6m (3,500 feet) (Ozolins & Smith, 1968, p.51). It was felt that emissions taking place at cruise altitude (above about 1,060.6m or 3,500 feet) were not of immediate concern to air pollution authorities. An area of 19.2km (12 miles) radius can be considered as the most likely area in which operations will be conducted below 1,060.6m (3,500 feet) (Bourke, 1973, p.75). Distances to 1,060.6m (3,500 feet) during departures will depend upon aircraft types,

TABLE 34

Total Annual Flights by Modes of Power at the Subang International Airport, 1972-75

Year	Jet				Turbo-Propeller				Piston				Total Flights
	4 engines		2 engines		4 engines		2 engines		4 engines		2 engines		
	No. of flights	% of total	No. of flights	% of total	No. of flights	% of total	No. of flights	% of total	No. of flights	% of total	No. of flights	% of total	
1972	3,393	18.8	7,703	42.6	52	0.3	4,383	24.3	84	0.5	2,449	13.5	18,064
1973	3,430	14.5	10,843	45.6	51	0.2	3,926	16.5	66	0.3	5,454	22.9	23,770
1974	4,393	18.5	10,681	45.1	27	0.1	4,278	18.1	37	0.2	4,278	18.0	23,694
1975	5,006	22.9	10,871	49.7	221	1.0	3,819	17.4	79	0.4	1,884	8.6	21,880

(source: Malaysian Civil Aviation Department)

Table 35

Estimated Emission of Major Pollutants by Aircraft Using the Subang International Airport, 1972-75 (tons)

Year	Carbon monoxide		Hydrocarbons		Oxides of nitrogen		Particulates		Total Pollutants
	Total pollutants	% of total	Total pollutants	% of total	Total pollutants	% of total	Total pollutants	% of total	
1972	212.2	34.5	277.1	45.0	51.4	8.4	74.5	12.1	615.2
1973	336.2	38.3	396.1	45.1	61.0	7.0	84.2	9.6	877.5
1974	308.1	35.8	386.8	44.9	68.3	7.9	98.2	11.4	861.4
1975	254.9	31.3	380.4	46.8	70.6	8.7	107.7	13.2	813.6

(source: Malaysian Civil Aviation Department) weights, operating procedures and meteorological conditions of wind and temperatures.

Table 35 indicates that the total amount of the four major pollutants over the 1972-75 period fluctuates between 615.2 tons in 1972 to 877.5 tons in 1973. However, in the last three years the annual total has exceeded 800 tons. The bulk of the pollutants from aircraft are in the form of carbon monoxide and hydrocarbons which make up for over 78 percent of total.

Compared with the amount of pollutants emitted from fuels supplied to Kuala Lumpur - Petaling Jaya (Table 27), that from aircraft is negligible. In 1975, the amount of air pollution from aircraft operating from the International Airport at Subang was only 0.7 percent of that produced by fuels supplied to Kuala Lumpur - Petaling Jaya. It is highly unlikely that this figure would increase to any significant degree even if the air pollutant emissions of aircraft from the Royal Malaysian Air Force base at Salak South and the aerodrome at Segambut had been considered. Thus, it is apparent that the amount of pollution from aircraft is at present only a minor contributor to the total emissions of pollutants from the use of fuels within Kuala Lumpur - Petaling Jaya. Nevertheless, the effects of air pollution from aircraft upon the immediate environment of the airport should not be under-rated.

3.6 Possible Air Pollution from Tin Mining Activities and Solid and Liquid Wastes

In order to present a more complete view of the pollution situation in the area, consideration of other possible sources of air pollution is necessary. This section deals briefly with the open cast tin mines and solid and liquid wastes as likely sources of air pollution. The former is usually identified with dust while the latter is significant in its contribution to odour type pollution (see Chapter 1). However, as available data do not permit any form of quantitative estimate of air pollution to be made from these sources, only qualitative assessments are given.

3.6.1 Possible Air Pollution from Tin Mining Activities

Where land has been worked at the surface, whether for gravel-pumping or hydraulicking, the resultant landscape consists of a series of abandoned mining pits filled with water. Where dredging has been employed, the slime is accumulated in separate paddocks, and the final result after mining is a series of small flat terraces of varying levels consisting of unconsolidated loose sand. In Kuala Lumpur - Petaling Jaya and its surrounding areas, this has been observed to be an additional source of air pollution particularly in the afternoon when winds are strong or when trucks and other motor vehicles pass over it. One such area was that stretching along 5½ Mile Jalan Ipoh not far from Batu Caves. Qualitative observations here indicate that visibilities are very much reduced particularly towards the evening following a windy afternoon.

The rapidity with which plants are able to establish themselves on mined land depends not only upon the nature of the soil, but also upon the water supply. On unslimed, sandy areas, natural regeneration is extremely slow and several years elapse before the ground is covered with even a stunted growth of vegetation; but in slimed areas the process takes place more rapidly and a larger range of plants is able to establish itself. On such soils a number of indigenous, as well as certain imported species, have been proved to do well under experimental conditions (Report on River in the Federated Malay States, 1928). Among the indigenous plants are the tall grasses such as Saccharum (Malay: Teberau), Coelorrhachis, Phragmites (Malay: Gedabong) and bamboos, as well as such ubiquitous species as lalang (Imperata cylindrica), buffalo grass, carpet grass, Eragrostis and Digitaria.

Experiments at rehabilitation of such land by reafforestation have shown that it is both expensive and difficult (Ooi, 1967). So far the only practical use to which mined-over land has occasionally been put is for Chinese market-gardening which is quite extensive on the outskirts of Kuala Lumpur.

Recently an attempt has been made by the City Hall Authority to convert a large disused mining area northeast of Kuala Lumpur into a park similar to the present Lake Garden. This is one practical way of rehabilitating a desolate mining land while at the same time contributing to the aesthetic value of the area and in term of recreation.

3.6.2 Waste Disposal in Kuala Lumpur - Petaling Jaya

Another problem resulting from increasing urbanization is that of waste disposal.

(a) Sewage and Waste Water Disposal: In Kuala Lumpur, a water-borne sewerage system was brought into operation in 1958 and, together with the extension constructed since, about 30 percent of the population is now served by the system. Domestic sewage is given primary treatment at the Pantai Sewage Treatment Works before being discharged into the Sg. Kelang. Approximately 11,000 septic tanks are in use within the former city boundary,[1] serving a

1. This refers to the old boundary of the Kuala Lumpur Municipality before it was declared Federal Territory in 1974.

population of about 75,000. The sewerage system and the septic tanks were designed to accept both foul and sullage water, as required by the City by-laws.

In Petaling Jaya, all foul wastes from the population of approximately 94,000, drain either to septic tanks or to Imhoff tanks. The septic tanks normally serve individual properties while the Imhoff tanks treat flows from group of properties such as rows of shophouses and Government housing areas. Whilst the by-laws require that the sullage water be connected to the septic tanks and Imhoff tanks, the latter were not designed to accept these flows and all sullage water is discharged into the surface water drains.

In addition to those served by a water-borne system, a significant proportion of the population have to use much less satisfactory systems. The 1970 Census recorded that 206,000 persons used the night soil bucket system; over 200,000 persons used pit or over-water latrines, and there were others for whom the facility used was not recorded, although it is probable that in most of these cases there was no facility available (Balfour & Sons, 1974).

Several authorities are employed in the collection of night soil and many methods used for its disposal. The Urban Services Department of City Hall collects nightly soil from over 6,000 buckets from all areas within the former city boundary except for Kg. Data Keramat, Ulu Kelang, Kg. Pandan Luar, and Ayer Panas.[1] Several purpose-made tankers operate the service and the night soil collected is transported to the Pantai Sewage Treatment Works for treatment. A private contractor is employed by the Urban Services

---

1. See Appendix I for place names.

Department to collect night soil from a total of over 1,400 buckets located in Dato Keramat, Ulu Kelang, Kg. Pandan Luar and Ayer Panas which are subsequently discharged at the Pantai Sewage Treatment Works. A number of local councils provide services to their own areas. The extent of the service provided is often determined by the resources of the authority and the importance they attach to the collection and disposal of night soil in relation to the other services provided.

In the squatter areas where there are over 16,000 night soil buckets in 1970, no night soil collection is made from them by any of the authorities (Balfour & Sons, 1974). Collection within these areas is generally carried out by a private contractor under individual arrangements made with each household. There are no records of the methods of disposal employed but it would appear that whilst some trenching is employed, the most frequent method is to discharge the night soil into a river or stream or disused mining pools.

(b) Solid Wastes: Population growth has had an equally dramatic impact in the area of solid waste disposal. This factor is coupled with the fact that as society becomes more affluent, the volume of materials it discards also becomes greater. Figures obtained over the past years indicate that the quantity of refuse disposed of per day ranges from about 2.0 lbs/head of population in European countries to 4.0 or 5.0 lbs/head in the United States (Kirov, 1968).

Information on the quantities of refuse and other solid wastes in the Kuala Lumpur - Petaling Jaya area are meagre. However, Lee (1975) indicated that the amount of refuse in Kuala Lumpur as collected by the Municipal vehicles had increased from about 150 tons/day in 1967 to about 270 tons/day by end of 1975. He envisaged that the extension of the refuse collection services to the Federal Territory during 1975 would increase the quantity collected to about 400 tons/day. Balfour & Sons (1974), using refuse generation ratios of 1.0 and 1.2 lbs/person/day for 1975 and 1985 respectively, suggest a figure of 305 tons/day for 1975 and 600 tons/day for 1985.

Officials of the Public Health Department of Petaling Jaya Town Board estimate that, on the average, about 80 tons/day of refuse are collected from the Petaling Jaya area alone. There are no records from which reliable estimates can be made of the quantities of waste collected by contractors from commercial and industrial premises. Likewise no records are available from new housing estates where refuse is collected by private contractors.

In a survey carried out by the City Hall (Lee, 1975), it was found that about 70 percent of the houses in Kuala Lumpur did own decent acceptable refuse bins whilst the rest used a varied assortment of cans, tins, and paper bags as refuse receptacles. Most shops in the commercial area favour the use of 44-gallon oil drums. Although the Municipal by-laws stipulate that the owner of every house shall provide and maintain in good order a sound, covered dustbin of a capacity of not more than three cubic feet (0.084 cubic metres) and of a pattern and material approved by the authority, it is most difficult to enforce this law particularly in the low income group.

The City Hall itself maintains a network of about 2,900 round bins of capacity 1.15 cubic metres ($1\frac{1}{2}$ cubic yards) each of which are placed 'strategically' all over the City. These are however becoming obsolete and more often than not unhygenic.

Normally baskets of refuse have to be lifted above the bin rim, which is 1.53m (5.0 feet) above the ground and often spillage occurs with a tendency for heavy baskets to be emptied on the ground. Also, the large bins have no covers to keep rain off the contents, which are also accessible to flies and vermin and give off a very strong smell. This is indeed very disturbing particularly when these bins happen to be close to open air restaurants and eating stalls. New large bins of a conveniently low height are however being introduced in order to minimize spillage.

At present, method of refuse disposal in Kuala Lumpur and Petaling Jaya is by controlled tipping. The dumping sites are at Salak South, 3¾ Mile Jalan Sg. Besi (for Kuala Lumpur) and at Sg. Way (for Petaling Jaya). Besides these official tips there are numerous instances of unofficial tips developing and of flagrant wayside dumping of rubbish.

Refuse disposal by controlled tipping can be both cheap and useful provided, of course, the process is carried out in accordance to well-established principles. However, where landfill operations are not as carefully controlled as is desirable, odours of partly decomposed refuse can become very offensive in the neighbourhood of the tip and inadequate compaction and covering of refuse leads to infestation by flies and vermin.

In the Salak South tip, the nature of refuse is such that the layers do not compact sufficiently to enable the collection vehicles to approach nearer than about 45.5m (50 yards) from the face of the tip. Despite the covering of the dumped refuse with about 15.2-cm (6-inch) thick layer of sand, the rate of such covering is slow due to the great amount of refuse being disposed of. Sometimes much of the sand delivered had to be used by the bulldozers to give firmness to the surface of the tip near the entry point particularly after rain which caused it to become soft. Also the sides and the face of the refuse tip cannot be covered as these are the working surface of the tip. These uncovered portions of the dumped refuse will give off a very strong smell nuisance from the decomposing refuse. Many live fly grubs were usually on the surface from which the refuse had been scraped, despite the efforts of workmen who spent most of their time going over the tip with stirrup pumps and buckets of insecticide mixture.

The combined tip for Sg. Way/Subang and Petaling Jaya located close to the junction of Jalan Kelang and the Federal Highway receives mainly household and vegetable wastes. A bulldozer is employed permanently on the site and the maintenance works carried out there are very much similar to those found at the Salak South tip.

To summarize, although no quantification with regard to the amount of pollutant emissions is possible from solid and liquid wastes and mining activities, they obviously represent potential sources of air pollution. Despite the comparatively low refuse generation rate and the availability of disposal sites around Kuala Lumpur - Petaling Jaya for future use, the maintenance of these sites requires rigorous controls in order to minimize odour probelms, vermin and flies. The night soil bucket, pit and over-water latrine systems are unsatisfactory. Besides contributing to odour problems, these methods expose the population to serious health risks. Air pollution from tin mining activities does not pose as serious a problem as waste and sewage disposals. Although areas of desolate wastes resulting from mining activities represent an additional source of particulate air pollution, they do not any more pose a threat once they are rehabilitated through overgrown, market gardening or conversion into parks. In areas where dredges have been employed however, natural plant regeneration is extremely slow. The possibility of air pollution from these areas is therefore greater and extends for a longer period.

3.7 Summary

The most important points arising from this Chapter may be summarized as follows:-

1. Transport, particularly motor vehicles, and industries respresent the two most important sources of air pollution in Kuala Lumpur - Petaling Jaya. Together they produce 99.3 percent of the major pollutant emissions. Emissions from aircraft, tin mining activities and waste disposals are relatively insignificant. This, and examination of pollutants emitted suggests that Kuala Lumpur - Petaling Jaya is subject to the Los Angeles type pollution.

2. Computation of total emissions and comparison of these figures with those obtained from other cities suggests that pollution in the Kuala Lumpur - Petaling Jaya area is of the same order as low to moderately polluted mid-latitude cities. However marked increases in energy use have occurred recently. The major parts of these have taken place in motor spirits and fuel oils; in terms of percentage of annual total, petroleum products account for over 87 percent of the total energy supply during 1975.

3. In addition, Chapter 2 indicates that, at least on the basis of U.S. derived forecasting technique, pollution potential is high. Hence, the problem of air pollution in Kuala Lumpur - Petaling Jaya is certainly a cause for concern which needs more serious attention than it has so far received.

CHAPTER FOUR

LEVELS OF SELECTED POLLUTANTS IN THE KUALA LUMPUR - PETALING JAYA AREA

4.1 Introduction

It has been suggested in the previous two chapters that on the basis of standard application of U.S. derived forecasting technique, Kuala Lumpur - Petaling Jaya climate has a high potential for air pollution; and that the emissions are of the same order as low to moderately polluted mid-latitude cities. Hence an investigation of actual levels of pollution in the study area at this stage would be worthwhile. A secondary aim of the Chapter is to estimate the effects of meteorological variables and emission characteristics on levels of these pollutants in space in time.

Three types of measurements are available with regard to levels of air pollution in Kuala Lumpur - Petaling Jaya and its environs. These are: (1) the measurements of dustfall in and around Batu Caves, 11km (7 miles) north of Kuala Lumpur central city; (2) the measurements of sulphur dioxide (SO_2) in and around an industrial section of Petaling Jaya; and (3) the measurements of respirable dust particulates in the City area (Figure 37). The first two projects began during 1972 and were carried out by the Factory and Machinery Department Malaysia; the last one has been undertaken by the author during the period of fieldwork. Hitherto, there has been little (if any) concerted effort by any Government agency to draw up a long term air pollution monitoring programme to cover the whole of Kuala Lumpur - Petaling Jaya. The first two projects by the Factory and Machinery

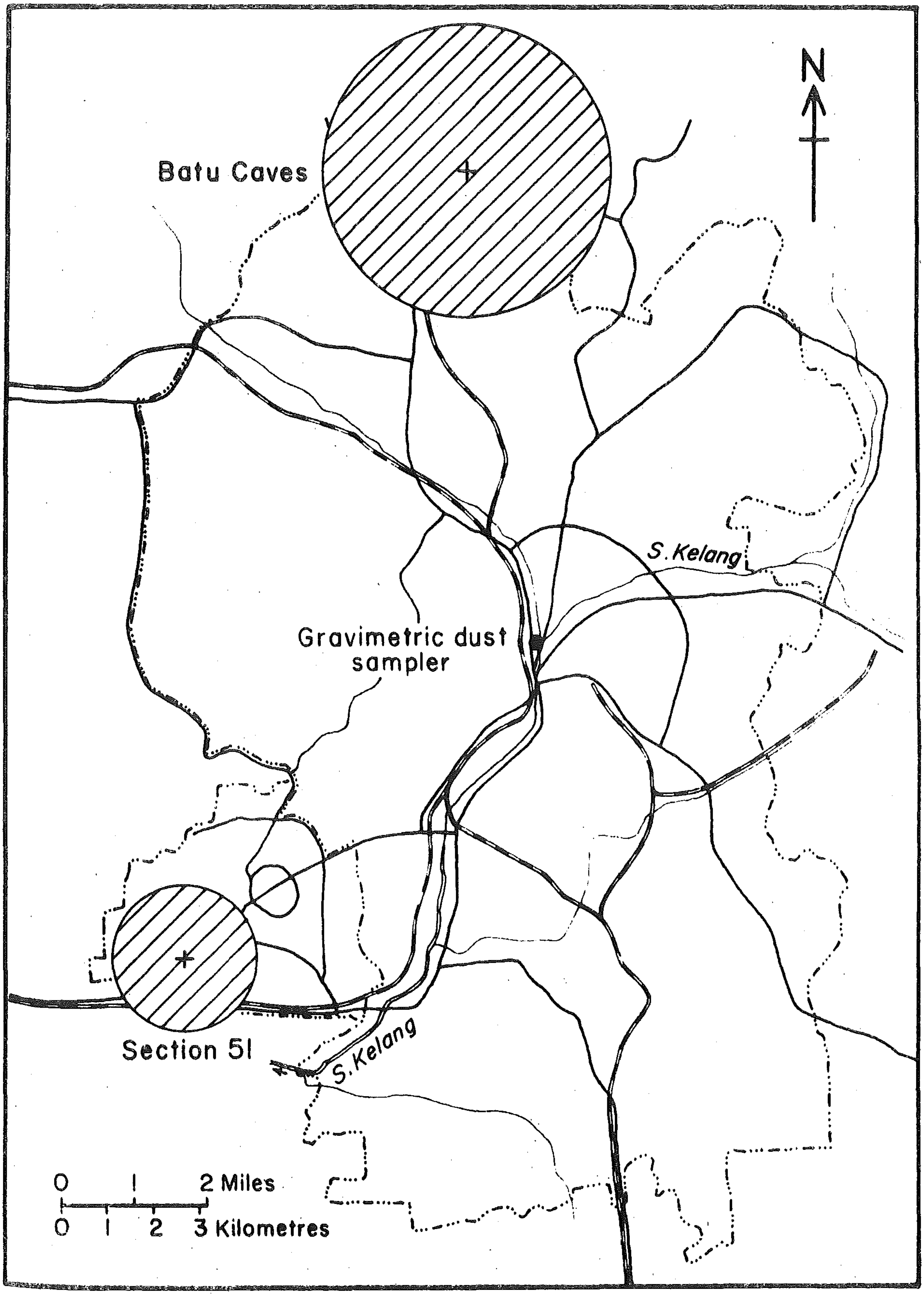


Figure 37: Location of Batu Caves, an industrial section (Section 51) of Petaling Jaya and the gravimetric dust sampler

Department Malaysia came about as a result of public complaints of excessive dust in the Batu Caves area and suspected excess of SO_2 emissions in the vicinity of an industrial section of Petaling Jaya straddling the Federal Highway to Kelang.

4.2 Dustfall Measurements in and around Batu Caves

For many years, particulate pollution from quarries and cement works has caused a great deal of concern among residents living in and around Batu Caves. At present there are four quarries, one cement works and one sawmill all located within a radius of less than 0.8km (0.5 mile) of one another. In view of the situation, the Factory and Machinery Department Malaysia set up several dust samplers around the works in order to assess the seriousness of pollution and to estimate the extent of areas affected.

4.2.1 Dustfall Data

Dustfall was collected using 10 deposit gauges within a 3.0-km (2.0-mile) radius of the source area (Figure 38). The design and siting of these gauges were in accordance with those prescribed by the British Standard Institution (1969). Data collection began towards the end of 1972 and is still in progress. Analyses presented in this Chapter cover the period between January, 1973 and December, 1975 inclusive.

There are several limitations to the deposit gauges as measuring instruments of atmospheric pollution. First, the catchment vessels are often not deep enough in comparison with their diameter to prevent the wind from sweeping out some of the deposit which may be left dry in the gauge after the rainwater has been drained away into the bottles underneath. A second

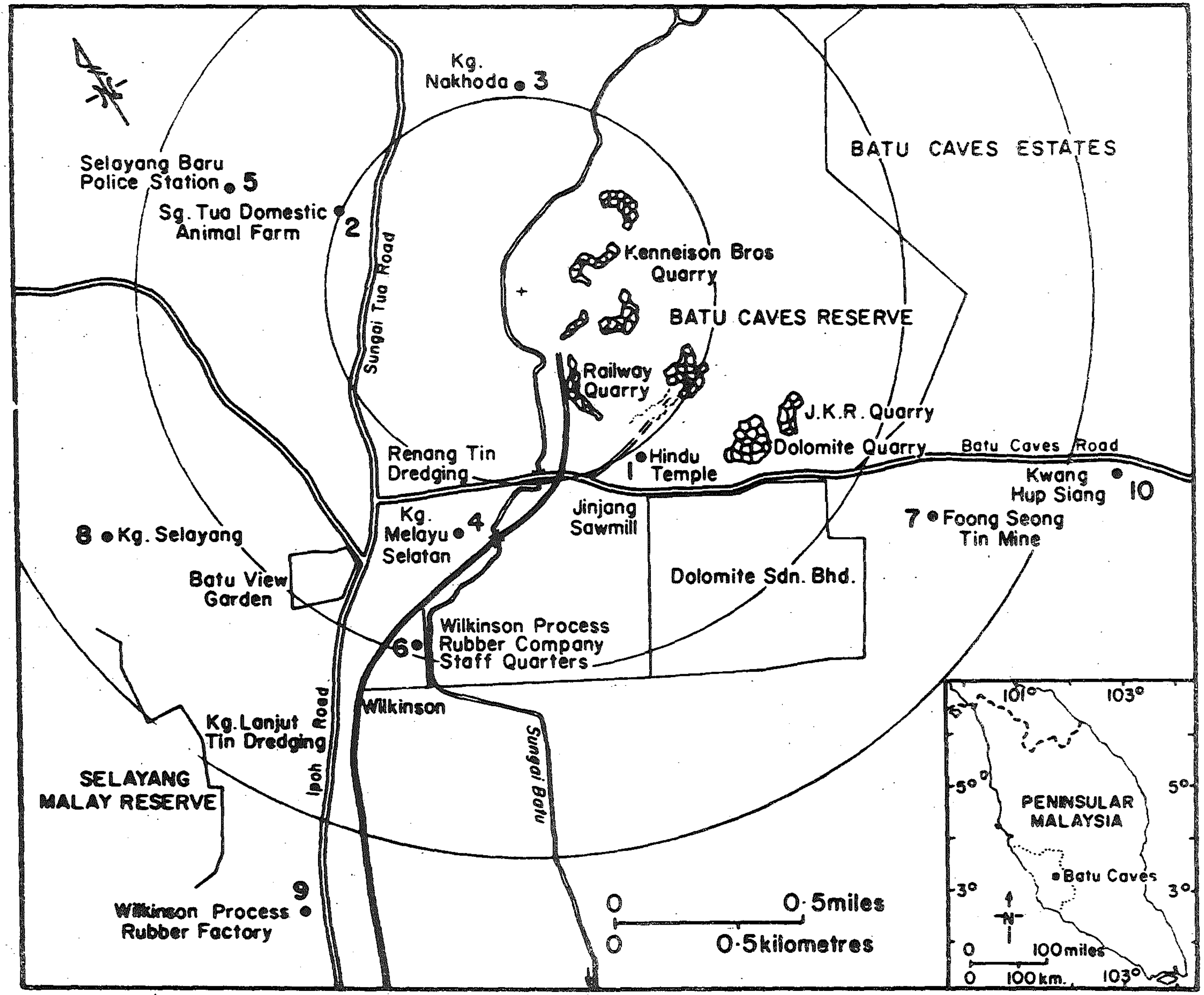


Figure 38: The Batu Caves area showing quarry and cement works and location of deposit gauges

point for consideration is the need for great care in the collection of the deposited matter from the basin, connecting tubes and bottles, especially where the amount is not large. It is not always that a trained observer cleans out the basin, and neglected particles which seem small may have a serious effect on the total. But even when all precautions have been taken, the results still do not give a true picture of the pollution in the air. When the air is perfectly calm, so that no impurities are carried over the gauge, it can then only measure what falls into it from a super-incumbent column of air. When there is wind, much of the atmospheric pollution must be carried along without being deposited. In either case, the deposit collected will be below the true amount in the air.

Despite all the shortcomings discussed above, there are at present a number of towns which make measurements of atmospheric pollution by means of the deposit gauge. It is felt that in the absence of a more reliable set of data, results from deposit gauges could still be usefully employed to indicate gross patterns of dustfall in an area and are therefore useful.

In the discussion that follows, an attempt is also made to examine the relationship between dustfall concentration pattern and wind measurement. As the latter is not available in the Batu Caves area, data from both surface and upper air as recorded at Subang airport have been used to give an approximate indication of the prevailing wind direction.

4.2.2 Spatial Distribution of Dustfall

Figure 39 shows the concentration of dustfall in and around Batu Caves averaged over the three-year period. Although the

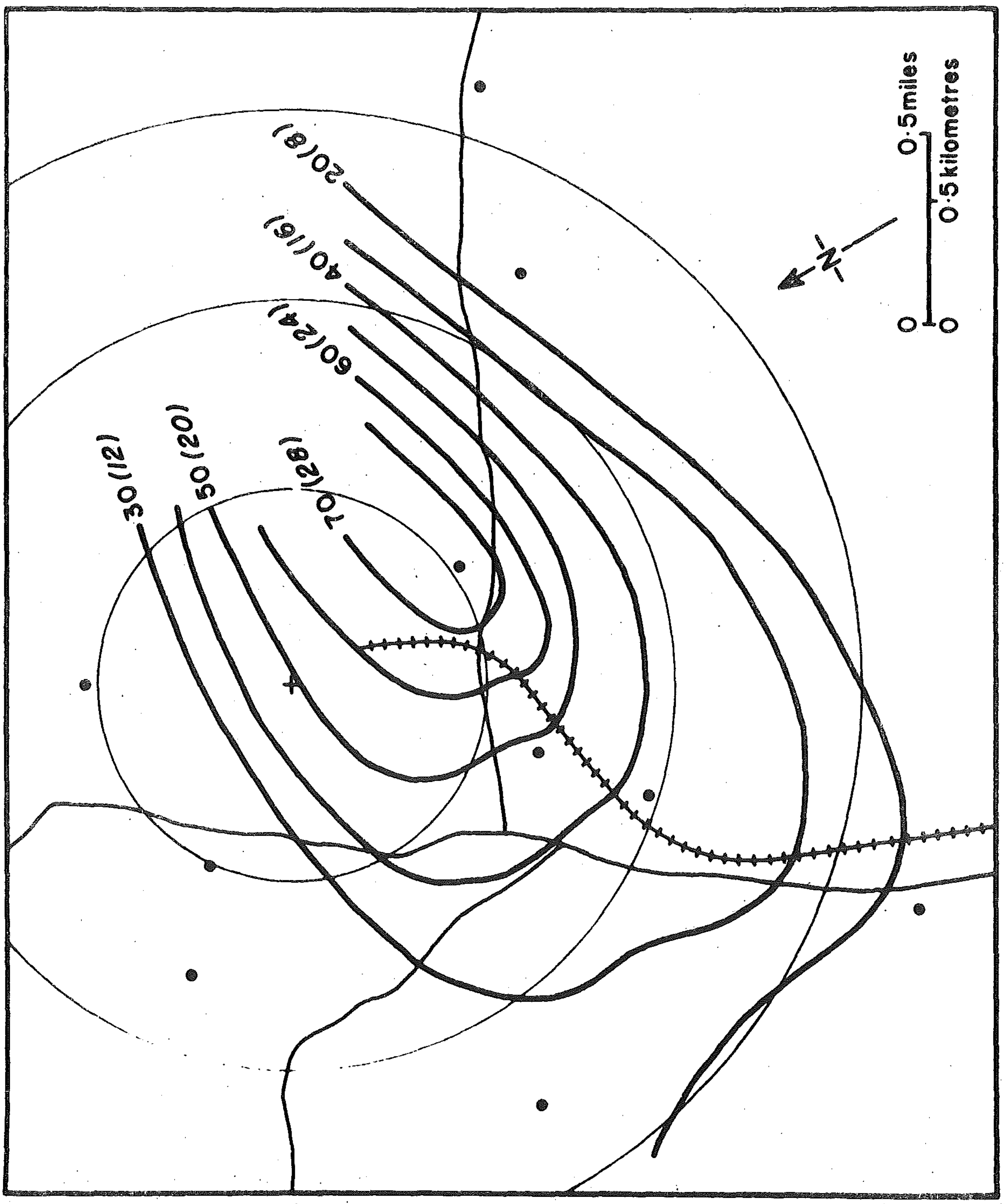


Figure 39: Average concentrations of dustfall in and around Batu Caves, averaged over three years (1973-75). Figures are given in tons/mi^2/month. Equivalent values in tonnes/km^2/month are given in brackets

isoline map in Figure 39 is somewhat crude due to the limited number of sampling stations, it does present a general picture of the average pattern of dustfall in the area. On the average, the mean monthly dustfall for the area within approximately 3.0-km (2-mile) radius of Batu Caves was 12 tonnes/km^2 (30.2 tons/mile^2). Station 1 (The Hindu Temple), which is nearest the source, recorded the highest fallout with 30.4 tonnes/km^2/month (76.6 tons/mile^2/month). The amount decreased with increasing distance away from the Hindu Temple. An area of relatively high concentration was observed WSW of the source area along the railway line and the main north road to Ipoh. One probable explanation for this pattern was the effect of the limestone hill barrier as well as the deflection of the 'prevailing' westerly winds by it at the source area (Table 36).

Another feature of the average concentration patterns was the rapid decrease of fallout along the Batu Caves Road between Station 1 and Station 7 (Foong Seong Tin Mine). A reduction of 24.6 tonnes/km^2/month (61.9 tons/mile^2/month) was observed between these two stations. Comparisons of Station 1 and Station 6 which is about the same distance away as that of Station 7 from Station 1 but situated west of the source area showed that the reduction was only 15.2 tonnes/km^2/month (38.4 tons/mile^2/month). This is illustrated further by the monthly variation of fallout for selected stations north (Station 5), west (Station 6), and east-south-east (Station 7) of the source area (Figure 40). Two factors could contribute to this pattern: (1) the physical barrier imposed by the limestone hills; and (2) the presence of vegetation in the Batu Caves Reserve and the Batu Caves Estate which act as dust filters especially when aligned in a perpendicular direction to the prevailing wind. Although specific studies to assess the extent

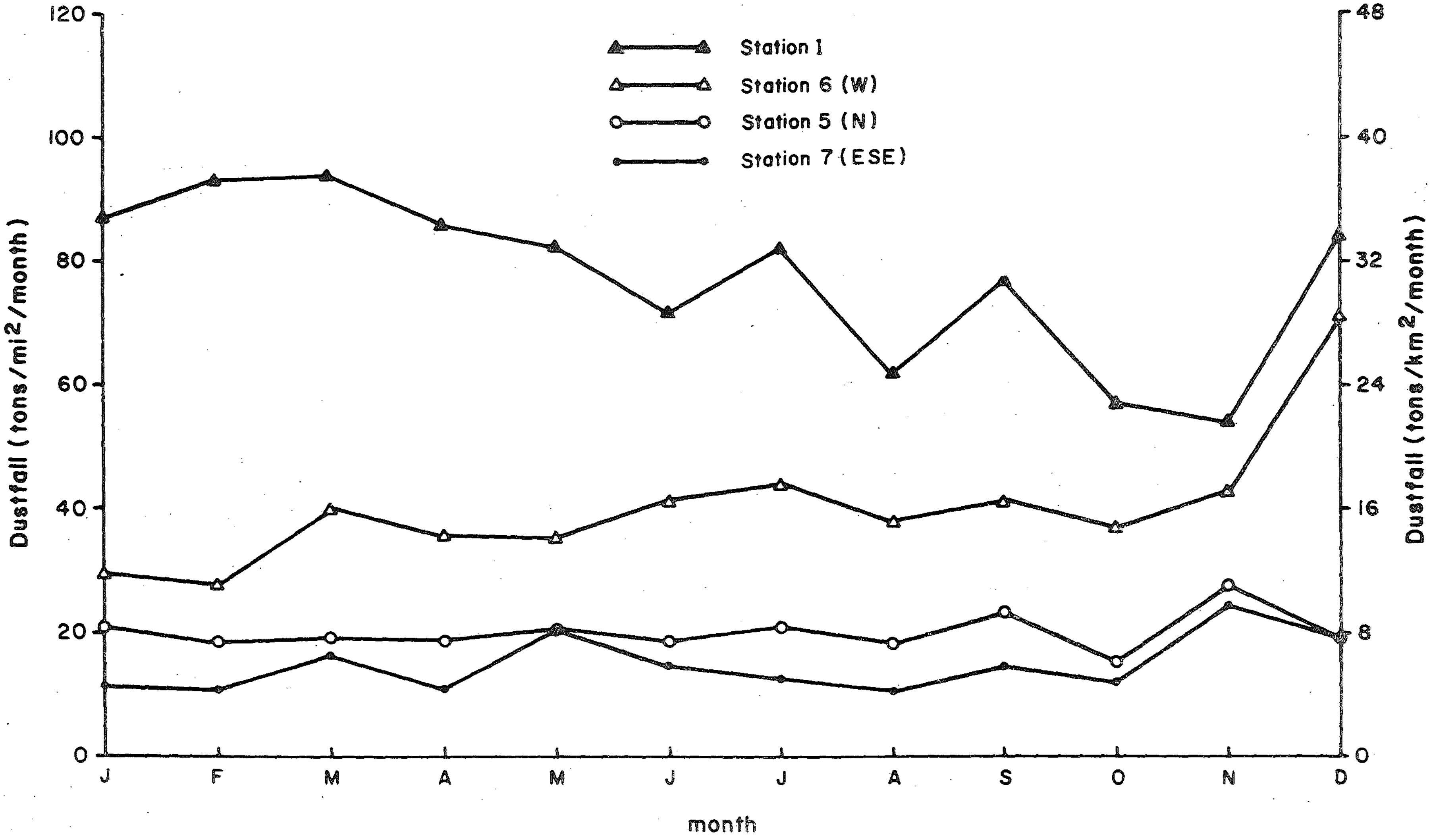


Figure 40: Monthly variation of dustfall for selected stations in different directions but of approximately the same distance from source area. Station 1 is also included.

of the effect of the Batu Caves Reserve and the Batu Caves Estate upon dustfall particulates are not available, an inference from other studies (e.g. Kuhn, 1959; Wainwright & Wilson, 1962; Pluss & Strauss, 1972) suggests that this could well be the case.

TABLE 36

Average wind directions (in percent) at the surface and at 303-m level in Subang. Data for upper winds are based on the 1330 hours (L.S.T.) readings

Height	N	NE	E	SE	S	SW	W	NW	Calm
Surface	2.6	3.0	6.0	5.5	7.0	4.5	7.5	9.5	54.4
303m	7.4	4.2	6.7	7.9	19.3	16.1	19.0	18.2	1.2

(source: Malaysian Meteorological Service)

Kuhn (1959), for instance, found a 75-percent reduction of dust particle count over a 182-m (600-foot) wide strip in Leipzig, while studies of Hyde Park in London reveal that this green area of only 2.6 square kilometer (1.0 sq. mile) reduces smoke concentration by an average of 27.0 percent (Wainwright & Wilson, 1962). Russian studies have also demonstrated the extent to which park areas can reduce particulate air pollution. 'Sanitary Clearance Zones' built around factories cleanse the air; gardens and parks in the vicinity of factories can lower the local dust content in the air by as much as 40.0 percent or more (Sokolovskii et al, 1966).

Stations north of the source area were intermediate in character with regard to fallout receipt. The average fallout for Stations 2, 3 and 5 was 8.7 tonnes/km^2/month (21.9 tons/mile^2/month).

The corresponding figures for Stations 4 and 6 east of the source area were respectively 19.7 and 15.2 tonnes/km^2/month (49.7 and 38.2 tons/mile^2/month); that of Station 7 was 5.8 tonnes/km^2/month (14.7 tons/mile^2/month).

Figure 41 shows the average concentration patterns of dustfall in the Batu Caves area by month. Although once again the isoline maps of fallout are necessarily crude, they do reflect the effect of physical barriers imposed by the limestone hills near the source, and that of the prevailing winds. In all of the 12 months the WSW-orientation of the dustfall concentrations is evident. The rapid decrease of fallout from Station 1 to Station 7 as indicated in the annual pattern (Figure 39) is also featured in the monthly average patterns.

It must be pointed out however that although the general pattern of fallout does suggest a single source hypothesis, the major source being the quarries and cement works and sawmill at Batu Caves, other potential sources of pollution are also present immediately outside the gauged area. These include sawmills, wood-product factories and mining areas to the south and southwest of Batu Caves. Undoubtedly these sources also contribute to the concentration of dustfall within the gauged area but their exact proportion is not known.

An attempt was also made to see if dustfall concentrations are in any way related to precipitation amount. As precipitation records in or near Batu Caves were not available for the observation period, those of Subang Airport were used. Linear correlations were performed on the monthly data of dustfall and precipitation amount for the 1973-75 period and results indicate that for the whole area generally the r-value was 0.0686; the

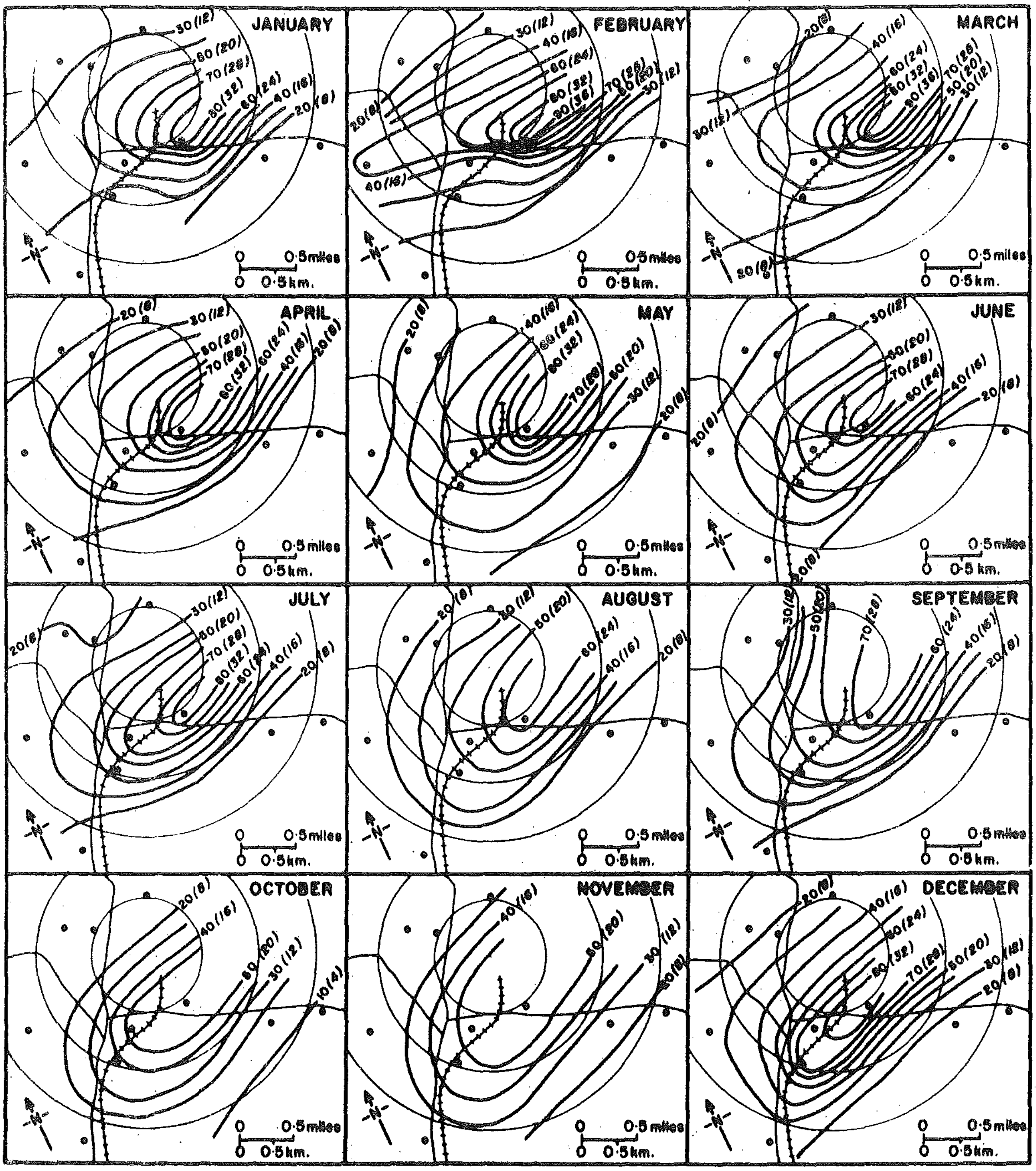


Figure 41: Monthly concentrations of dustfall in and around Batu Caves, 1972-75. Figures are given in tons/mi^2/month with their equivalent values in tonnes/km^2/month given in brackets

corresponding value for Station 1 (The Hindu Temple) was 0.0819. A linear correlation between the average values of precipitation and dustfall for the years 1973-75 over the 12-month period shows an improvement in r-value for the whole area generally, but a decrease for Station 1. The r-values are respectively 0.2059 and 0.0469 neither of which is statistically significant at the 0.05 level. It is worth noting that despite the low r-values, in all cases the relationship between dustfall and precipitation amount is always positive. This, of course, could be due to sheer chance. Alternatively however, this could be due to the generally more stable atmospheric condition and hence less pollution dispersion when rain occurs.

4.2.3 Comparisons with Results from Elsewhere

Several authors (e.g. Pluss & Strauss, 1972, p.167) have suggested 2.0 tonnes/km^2/month (5.0 tons/mile^2/month) as a reasonable value for rural areas, 6.0 tonnes/km^2/month (15.0 tons/mile^2/month) for residential and light industrial areas, and upwards of 10.0 tonnes/km^2/month (25.0 tons/mile^2/month) for heavy industrial areas. The proposed figures for Malaysian ambient air quality standards are: 3.2-4.0 tonnes/km^2/month (8.0-10.0 tons/mile^2/month) for residential zone, 6.0 tonnes/km^2/month (15.0 tons/mile^2/month) for common zone, and 12.0 tonnes/km^2/month (30.0 tons/mile^2/month) for industrial zone (Aziz Ahmad, Director-General Factory and Machinery Department Malaysia, 1975 <u>Personal Communication</u>). On the basis of the concentration pattern of dustfall averaged over the three-year period, most places within 2.4-km (1.5-mile) radius of the sources in the Batu Caves area already far exceeded the values recommended for residential and light industrial areas.

Table 37 which has been reproduced from Katz (1963) shows the mean monthly dustfall in various cities for further comparison. Figures given in this table however are somewhat dated. Recent reports indicate that there have been drastic reductions with regard to atmospheric particulates in certain American and European cities particularly after the 60's. The better visibilities of major U.S. cities for example have been associated with local efforts at air pollution abatement and substitution of oil and gas for soft coal in production of heat (Holzworth, 1961; Beebe, 1967). Brazell (1964), Wiggett (1964) and Freeman (1968) have suggested that London's improved visibility may be due to enforcement of the air pollution ordinances of 1954 and 1956. Similar reductions in atmospheric particulates following efforts at air pollution abatement have also been observed in other English cities (Atkins, 1968; Corfield & Newton, 1968). Whether or not the Clean Air Act of 1956 has been responsible for substantial improvements in air quality in Britain has recently been discussed by Auliciems & Burton (1973). They argue that improvements in air quality would have occurred anyway as a result of socio-economic factors that have been leading to increased use of oil and fuels other than coal in industry, and a displacement of the coal fire as the normal form of domestic heating. In any case, more recent data for North American and British cities would demonstrate even more the excessive nature of the dustfall at Batu Caves.

4.3 Sulphur Dioxide (SO_2) Measurements in and around an Industrial Section of Petaling Jaya

Sulphur dioxide (SO_2) is regarded as being one of the more serious and widespread of all air pollutants. It is emitted during

TABLE 37

Mean Monthly Dustfall in Selected Cities

City	Year	Mean dustfall	
		tons/mi^2/month	tonnes/km^2/month
CANADA			
Sydney	1958	53	21.0
Montreal	1960	60	23.8
Ottawa	1956-57	31	12.3
Toronto	1956	50	19.9
Hamilton	1958	34	13.5
Windsor	1955	55	21.8
Winnipeg	1958	49	19.5
Vancouver	1957	21	8.3
UNITED STATES			
New York	1956	85	33.7
Detroit	1956	67	26.6
UNITED KINGDOM			
Glasgow	1954	73	29.0
Birmingham	1954	93	36.9
Manchester	1954	97	38.5
London	1954	112	44.5
BATU CAVES			
Area within one-mile (1.6-km) radius of the source area	1975	38	15.1
Area within two-mile (3.2-km) radius of the source area	1975	30	12.0

(source: Katz, 1963, p.176)

the combustion of most fuels and can react in the atmosphere to form other undesirable compounds, including acids. Sulphur dioxide and its compounds can be corrosive and injurious to human and animal health and to vegetation. This section of the Chapter examines the concentration pattern of SO_2 in and around an industrial section (Section 51) of Petaling Jaya (Figure 42).

4.3.1 Sulphur Dioxide Data

Sulphur dioxide was measured using the lead dioxide method, originally known as the lead peroxide method. This method measures the reactivity of sulphur compounds in the air in terms of the rate of reactions with a prepared surface of lead dioxide. This is exposed to the air in a louvred box for a calendar month and the amount of sulphate formed is determined by chemical analysis. In the present study, all chemical analyses were carried out by the Chemistry Department Malaysia following closely the procedures prescribed by the British Standard Institution (1969).

For a long time, the Malayan Acid Works along the Federal Highway at Petaling Jaya has been suspected as the major source of sulphur dioxide in the area. In late 1971, 12 lead dioxide apparatus were set up in concentric rings around the acid works to see if this is in fact true (Figure 42). Data collection began in January, 1972 and is still in progress. Analyses in this section cover the period up to December, 1975.

4.3.2 Spatial Distribution of Sulphur Dioxide

Figure 43 shows the mean concentration patterns of SO_2 within approximately a 1.6-km (1.0-mile) radius of the Malayan Acid Works averaged over the four-year period. In general, concentration value of 0.02 parts per million (p.p.m.) and above

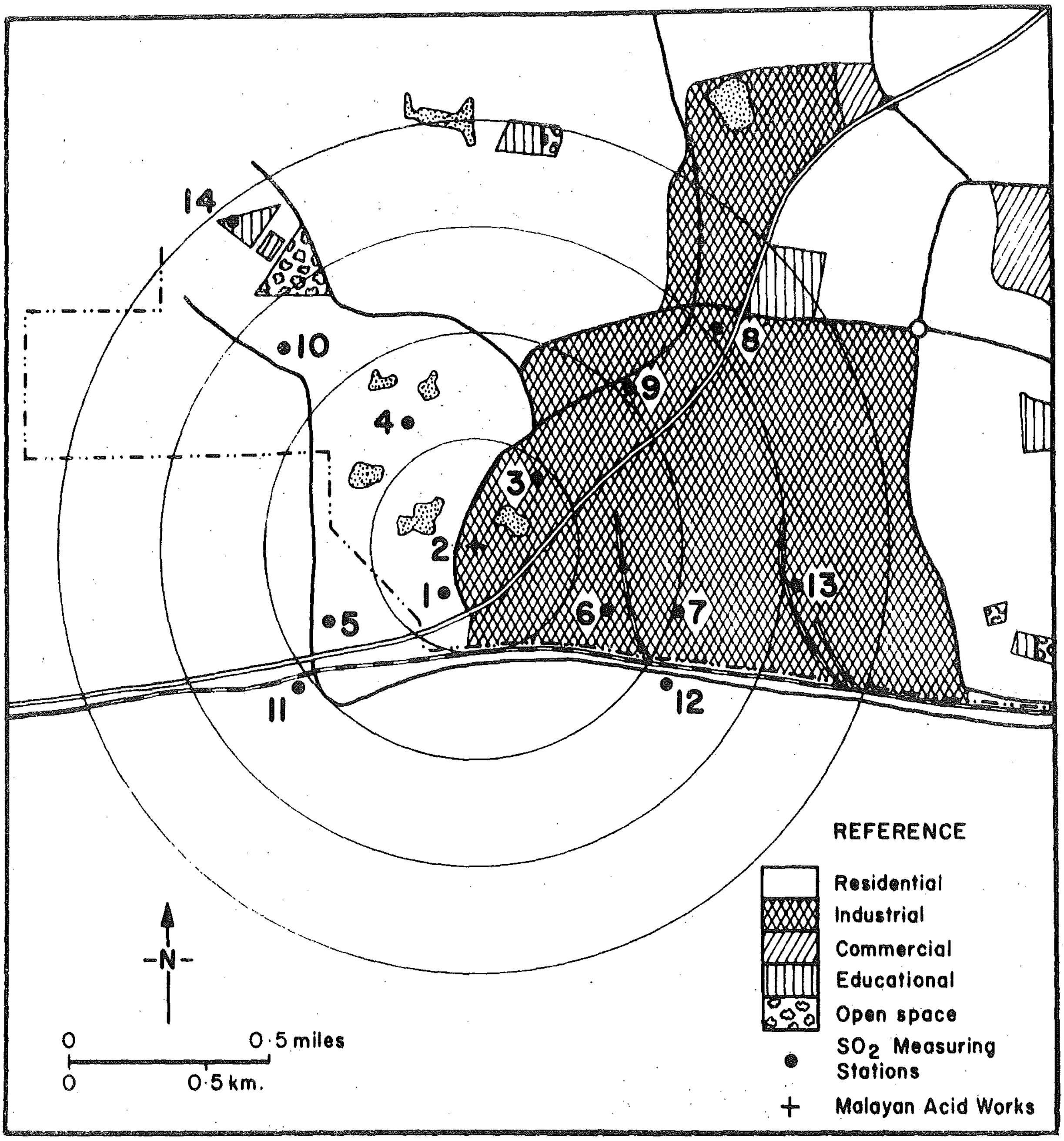


Figure 42: Location of sulphur dioxide (SO_2) Measuring stations in and around Section 51, Petaling Jaya, Selangor. Landuse is also indicated

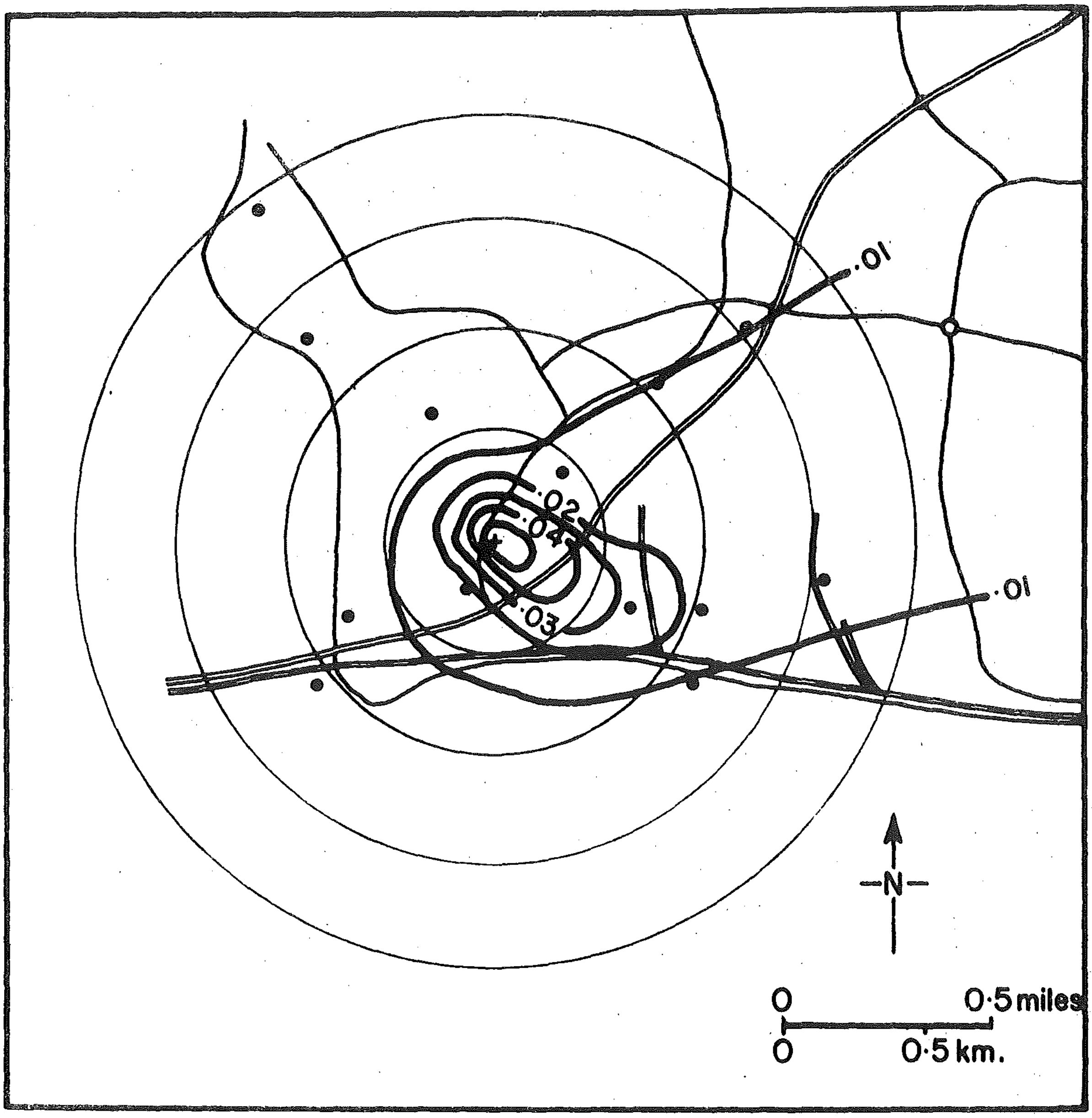


Figure 43: Mean annual concentration of SO_2 (p.p.m.) in and around an industrial section (Section 51) of Petaling Jaya, Selangor

was found to be highly localized and confined mainly within a 0.8-km (0.5-mile) radius of the Acid Works. Mean maximum concentration over the four-year period was 0.06 p.p.m. recorded at the Works itself.

Pollution at the Malayan Acid Works is caused mainly by waste gas from the production of about 40,650 tonnes (40,000 tons) of sulphuric acid a year (Staff of the Malaysian Business, 1975). In the process, sulphur, the raw material, is burnt in air to form SO_2. A catalyst is added to convert it to sulphur trioxide (SO_3), which then comes into contact with dilute acid to form sulphuric acid. This process is not 100-percent effective however with a small percentage of SO_2 and SO_3 being emitted into the atmosphere.

Further inspection of Figure 43 revealed that the spatial pattern was slightly elongated eastwards and that the relatively high concentrations of SO_2 coincided well with the industrial sector downwind of the Malayan Acid Works (Table 36). Figure 44 compares pairs of stations (one upwind and the other downwind, and both approximately the same distance from the Malayan Acid Works) in order to see if SO_2 concentrations were significantly different between the upwind and the downwind stations. Student's t-test was performed on data obtained from all the three pairs of stations and the results showed that in all cases, the difference was significant at the 0.01 level. It is however difficult to determine with any degree of certainty whether the relatively greater concentration of SO_2 east of the Malayan Acid Works has been due to emissions by factories within the industrial section or due largely to the effect of the prevailing westerly wind on SO_2 emissions from the Acid Works. Figure 43 indicates that both of these factors could be contributory to the resulting patterns but the latter

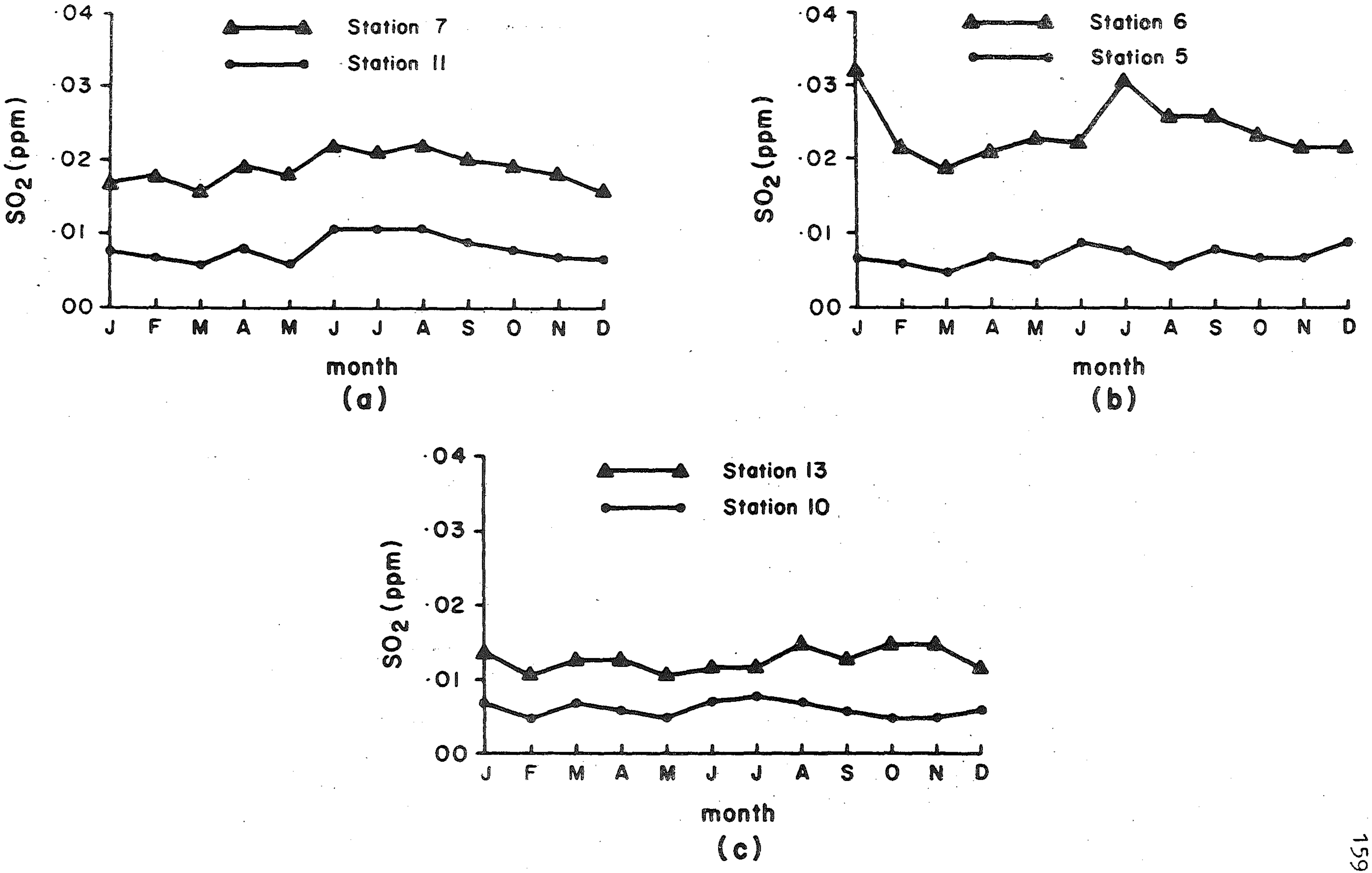


Figure 44: Sulphur dioxide concentration (p.p.m.) by month for pairs of selected stations to illustrate wind effects

appears to be the more likely cause.

Another feature of the average pattern shown in Figure 43 was the decrease of SO_2 concentration with distance away from the Malayan Acid Works. This was observed to be true in all cases irrespective of industrial or non-industrial areas, although the rate of decrease was somewhat less within the industrial part of the gauged area. This lends support to the contention that the Malayan Acid Works is the major source of SO_2 emission in the area. It also reflects the relatively greater influence of wind factor in the spatial distribution of SO_2 concentration within the gauged area.

Figure 45 shows the average concentration patterns of SO_2 by month. Generally these are similar to the mean annual pattern shown in Figure 43 and that the variation from one month to the next is very small. A persistent elongation eastwards is noted in all the 12 months.

An attempt was made to see if relationships exist between SO_2 concentrations and precipitation amounts. A linear correlation between monthly values of SO_2 and precipitation amounts for the 1972-75 period yields positive correlation for the Acid Works and the average of all stations. However, the respective r-values of 0.1065 and 0.2052 are not statistically significant at the 0.05 level. A linear correlation between the average values of precipitation and SO_2 for the years 1972-75 over the 12-month period shows better results. Negative correlations were found in both cases, the r-value being -0.3938 for the Malayan Acid Works and -0.5576 for the average of all stations. The latter value is statistically significant at the 0.05 level with a standard error of estimate (S.E.E. = $\pm$ 0.0025). It appears that on a longer time scale, there is a relationship between precipitation and SO_2 levels.

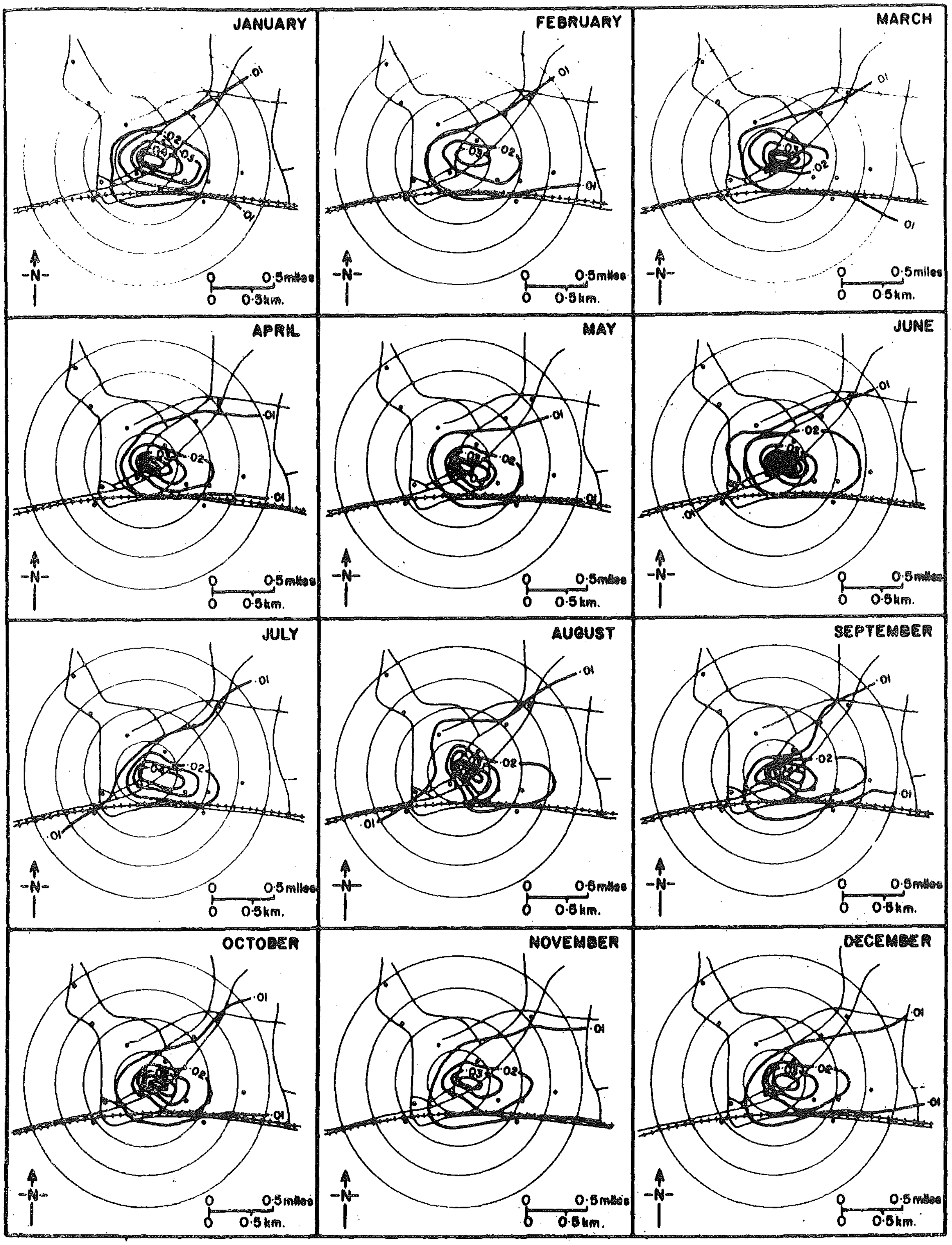


Figure 45: Monthly concentration of SO_2 (p.p.m.) in and around an industrial section (Section 51) of Petaling Jaya, Selangor

That is, wet months generally have low levels, probably as a result of a scavenging type process.

4.3.3 Adverse Effects of Sulphur Dioxide and Air Quality Standards

Despite uncertainties in the knowledge of the effects of air pollution on human health (Clarke & Sharp, undated), several attempts have been made to establish air quality standards. In the United States, the National Air Pollution Control Administration (NAPCA) published the first air quality criteria documents in 1969 (U.S. Department of Health, Education & Welfare, 1971). These documents deal with two of the most common air pollutants - sulphur oxides and particulate matter. The sulphur oxides study reviews and summarizes the results of over 300 studies and indicates that under the conditions prevailing in areas where the studies were conducted, adverse health effects were noticed when 24-hour average levels of SO_2 exceeded $300\mu g/m^3$ (0.11 p.p.m.) for three to four days. Adverse health effects were also noted when the annual mean level of SO_2 exceeded $115\mu g/m^3$ (0.04 p.p.m.). Visibility was reduced to about 8.0 km (5.0 miles) at SO_2 levels of $285\mu g/m^3$ (0.10 p.p.m.); adverse effects on materials were observed at an annual mean of $345\mu g/m^3$ (0.12 p.p.m.); and adverse effects on vegetation were observed at an annual mean of $85\mu g/m^3$ (0.03 p.p.m.).

Figure 46 shows the SO_2 concentration (p.p.m.) by month for two stations (Stations 2 and 6) having among the two highest values. If air quality standards suggested by the NAPCA are of any relevance to the study area, it is evident that for the study area generally the SO_2 concentrations have not yet reached a level which may be described as 'serious'. An examination of Figures 43 and 45 indicates that a concentration of 0.03 p.p.m. or more is highly

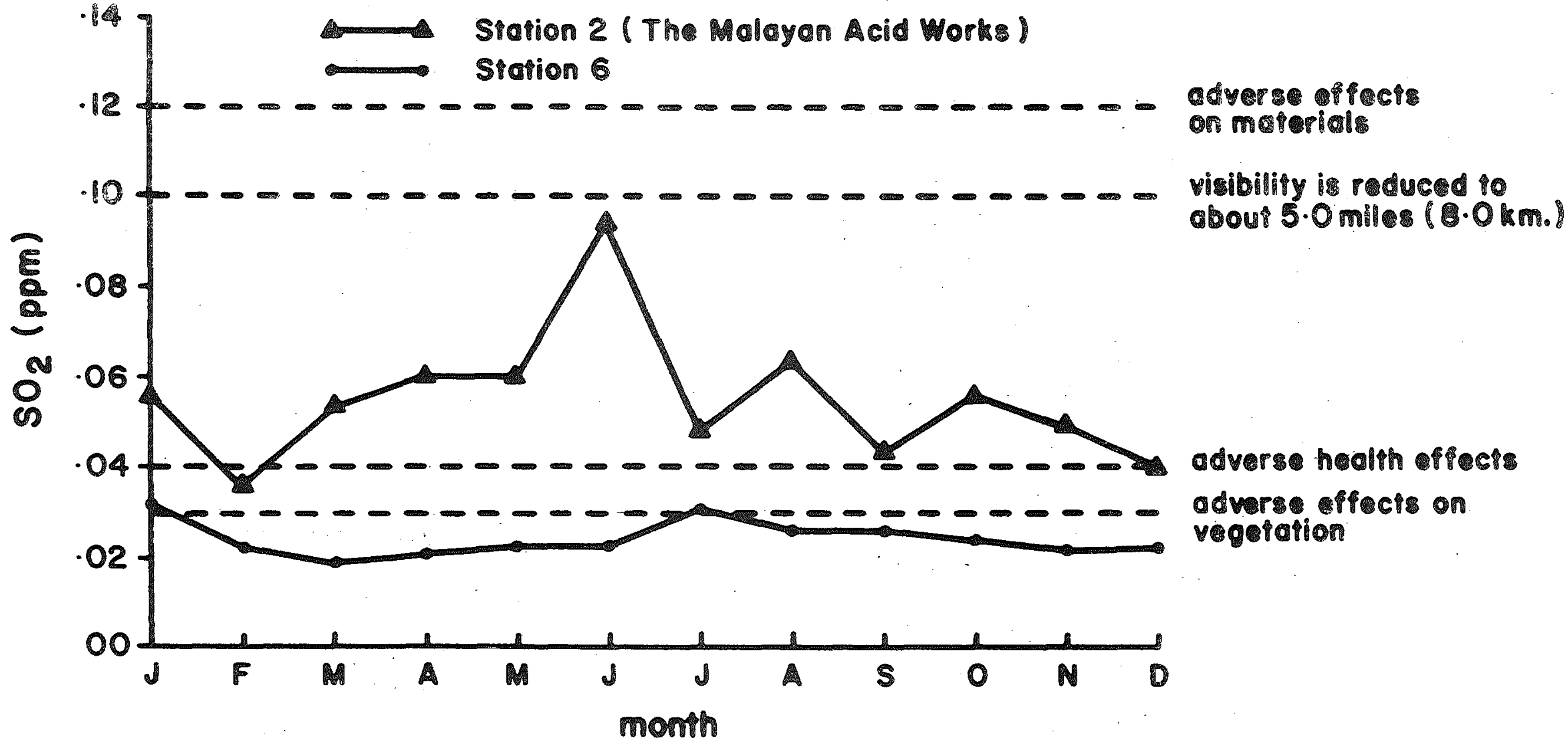


Figure 46: Sulphur dioxide concentration (p.p.m.) by month for stations 2 and 6. Mean levels of SO_2 which are known to affect materials, visibility, health and vegetation are also indicated

localized and confined to the immediate surrounding of the Malayan Acid Works only. However, measurements made at Station 2 (The Malayan Acid Works) showed that the SO_2 concentration there had already passed the acceptable levels for human health and vegetation. This situation is observed to be true for all months with mean maximum value of 0.09 p.p.m. recorded in June. This coincided with the month having the least rainfall (Table 10). Concentrations at Station 6, downwind of the Acid Works, are not as serious as those of Station 2 but in January and July the concentrations exceed 0.03 p.p.m. which can have an adverse effect on vegetation.

As yet there is no official air quality standard for Malaysia. However, a proposed Malaysian ambient air quality standard with regard to SO_2 put the average annual figure at 0.02 p.p.m. for all zones (residential, industrial and common zones) (Aziz Ahmad, Director-General Factory and Machinery Department Malaysia, 1975 Personal Communication). This figure coupled with those given by the NAPCA and the maps in Figures 43 and 45 should be able to give a rough indication about the SO_2 level in and around Section 51, Petaling Jaya.

4.4 Respirable Dust Particulates

When dusty air is inhaled, all the fast-falling particles and some of the small ones ($\leq 5.0\mu m$) are deposited in the nose and upper airways. Only small particles reach the respiratory region of the lungs. Large particles ($\geq 10\mu m$) are completely caught in the nasal passages, or at the back of the throat if the person is mouth-breathing (Bach & Lennon, 1972). Particles 5.0µm in diameter penetrate the airways as far as the volume of inhaled air carries them (Booker, 1967); small particles ($\angle$ 5.0µm) reach the bronchioles and alveoli with maximum retention in the size range of 0.8 - 1.6µm diameter (Bach & Lennon, 1972, p.6). Silicosis and other pneumoconioses arise from the incomplete removal of these particles, and the ensuing biological reactions to them. This section is concerned with these small particles, or more appropriately the respirable dusts, particularly with respect to their distribution and possible weather influences upon their concentration patterns.

4.4.1 Respirable Dust Particulate Data

Data on respirable dust particulates were obtained using the Casella type model 'B' personal size selecting gravimetric dust sampler (Plate 3). The dust-laden air is drawn through a 2.5-cm diameter filter disc at 1.9 litres/minute. A cyclone separator which precedes the filter disc selectively sizes the dust sample. The characteristic penetration curve for the cyclone corresponds closely with that recommended by the British Medical Research Council (Casella & Company, undated) and is shown in Figure 47. A diaphragm pump driven by a constant speed DC motor powered by a rechargeable 5.0 volt nickel-cadmium DEAC battery provides continuous suction for periods up to 10 hours. To obtain the dust loading, filters were weighed before and after use; the difference would represent the weight of total respirable dust particulates and is expressed in $\mu g/m^3$ after calculating the total volume of air passed through the apparatus. One advantage of the gravimetric dust sampler is that the aerodynamic separation process simulates that of the lungs, correctly taking into account the factors of particle size, shape and density and giving a percentage collection function similar to the particle deposition curve of the lung (Walton, 1971).

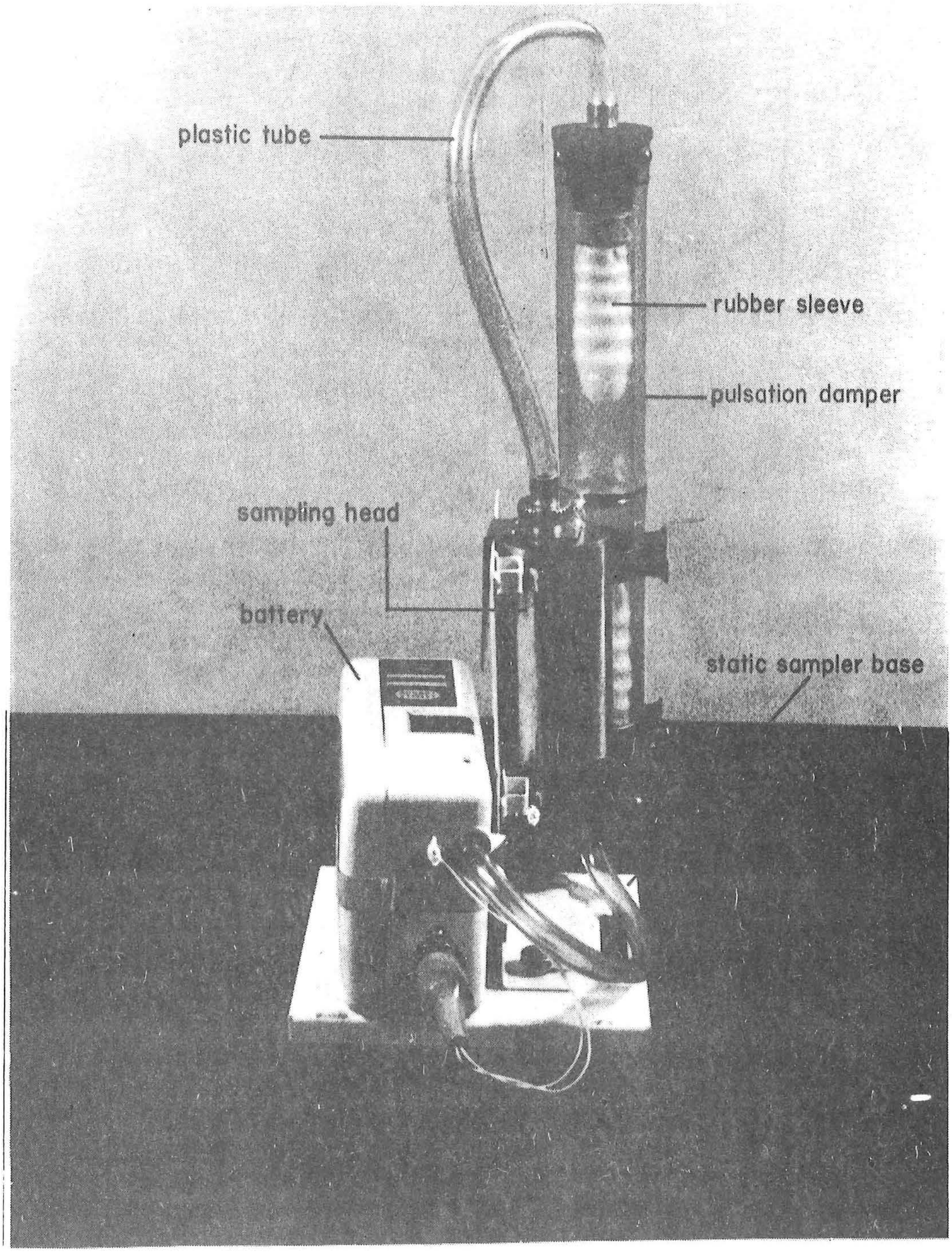


Plate 3: The Casella type model 'B' Personal size selecting gravimetric dust sampler

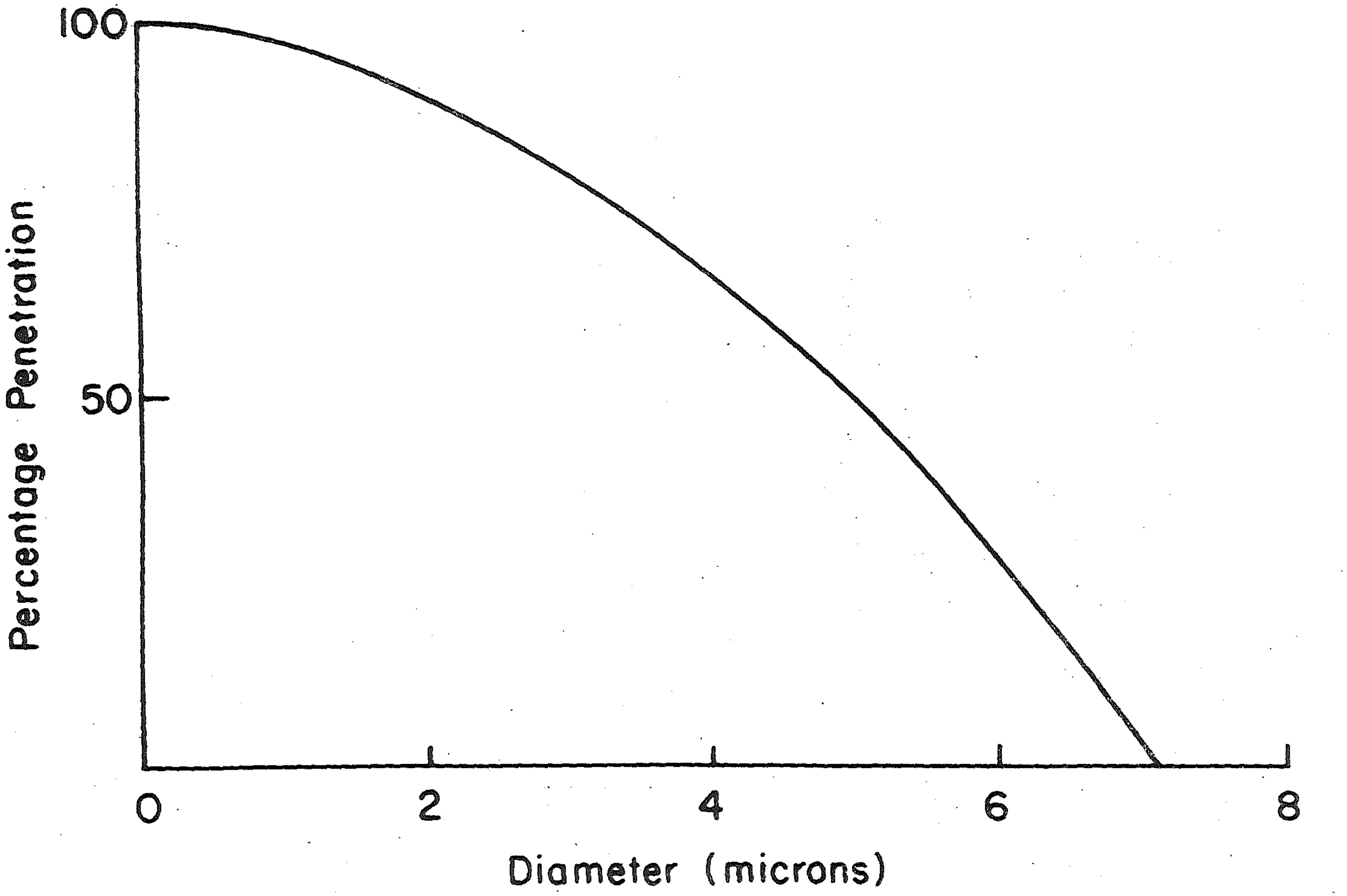


Figure 47: The characteristic penetration curve of the cyclone used in the selecting gravimetric dust sampler

The mass of fine dust provides a better index of the pneumoconiosis hazard than does the number count of small particles, and is a more precise measure less subject to personal bias (Walton, 1971, p.3). Other advantages of the gravimetric dust sampler as against other conventional dust measuring instruments have been discussed fully by Walton (1970 & 1971).

In all cases, the gravimetric dust sampler in the present study was fixed to a stand and placed at the chosen site. The longest record was for a site on a flat roof-top building of the Central Electricity Board, 9.14m (30 feet) above the ground, in the inner city of Kuala Lumpur (Figure 37). The sampling period was between 0730 hours local time (L.T.) and 1630 hours (L.T.) covering the period from 11th July, 1975 to 30th June, 1976 inclusive.

Variation of respirable dust particulates with height over the urban area was examined using samples taken at different levels within the Kuala Lumpur inner city. In addition to the site on the flat roof-top, two other sites within less than 200m (660 feet) from each other were also chosen (Figure 37). In these two cases, readings were taken respectively from 1.22-m (4-foot) and 50.29-m (165-foot) levels. Samples at the 1.22-m (4-foot) level were available from 23rd August, 1975 to 8th September, 1975 while those of the 50.29-m (165-foot) level covered the period between 19th July, 1975 and 20th August, 1975. In each case, samples were taken twice daily: 0730-1630 hours (L.T.) and 1630-0130 hours (L.T.). The afternoon readings from the flat roof-top were kept between 11th July, 1975 and 22nd August, 1975.

In order to examine if respirable dust concentration pattern is in any way related to landuse types, samples were also obtained for sites located in the different landuse types within Kuala Lumpur - Petaling Jaya. Besides samples in the inner city of

Kuala Lumpur (commercial area), readings were taken from an industrial area in Petaling Jaya (23rd August, 1975 - 21st September, 1975), a residential zone in Petaling Jaya (24th August, 1975 - 22nd September, 1975), and a parkland area in the Lake Garden (4th September, 1975 - 30th September, 1975). In all cases, samples were taken daily between 0730 hours (L.T.) and 1630 hours (L.T.).

4.4.2 Respirable Dust Particulate Distribution

The longest available record at a site in the inner city of Kuala Lumpur indicates that for the period of observation, mean concentration of respirable dust particulates was $77\mu g/m^3$ with a standard deviation of $17\mu g/m^3$. The median value was $75\mu g/m^3$ with lower and upper quartile values of $64\mu g/m^3$ and $88\mu g/m^3$ respectively. The monthly mean values of respirable dust particulates range from $66\mu g/m^3$ in July to $100\mu g/m^3$ in October. With the exception of July, however, the values do not generally fall below $70\mu g/m^3$. The median values, standard deviation and coefficient of variation for each month are shown in Table 38. Although comparable studies are not available and that there is a danger of comparing results obtained using different instruments on different time scale, Table 39 indicates that problems of particulate pollution in the central city of Kuala Lumpur can be quite serious when compared to those of mid-latitude cities. Furthermore, as measurements in the present case refer only to respirable dust particulates ($\leq 5.0\mu m$), figures for the total suspended particulates are likely to be greater than those given for respirable dust alone.

The day-to-day variations of respirable dust particulate concentration is shown in Figure 48. This indicates that contrary

TABLE 38

Mean, Median, Standard Deviation and Coefficient of Variation Values of Respirable Dust Particulates in the Kuala Lumpur Inner City, July 1975-June 1976

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
mean ($\mu g/m^3$)	66	75	73	100	92	72	80	78	73	80	80	71
median ($\mu g/m^3$)	70	80	75	100	90	75	80	70	70	80	80	70
standard deviation ($\mu g/m^3$)	17	22	17	18	19	13	18	15	10	14	13	11
coefficient of variation (%)	25.76	29.33	23.29	18.00	20.65	18.06	22.50	19.23	13.70	17.50	16.25	15.49

(source: Field Measurements)

TABLE 39

Average Annual Concentrations of Suspended Particulate matter ($\mu g/m^3$) at various cities

location	total suspended particulates		source
	mean	range	
Melbourne	51.0	20-100	Dixit *et al*, 1974
Sydney	55.0	13- 97	" "
Brisbane	40.0		Goodman & Hicks, 1973
Townsville	51.0		" "
Hobart	24.0		" "
Auckland, N.Z.		30- 34	Auckland Air Pollution Research Committee, 1974
Christchurch, N.Z.	40.0		Christchurch Regional Planning Authority, 1966
Dunedin, N.Z.		36- 48	Schwartz, 1975
New York	188.0	92-284	Kneip *et al*, 1970
Windsor, Canada		175-776	Munn *et al*, 1969
London, U.K.		158-294	Quoted by Dixit *et al*, 1974
Moscow		180-510	" "
Tokyo		154-227	" "
Bombay		215-269	" "
U.S. ambient air quality standards			Walther, 1972
Primary	75.0 (1 year)		
	260.0 (1 day)*		
Secondary	60.0 (1 year)		
	150.0 (1 day)*		
Malaysian ambient air quality standards (proposed)			Aziz Ahmad, 1975
Residential zone	100 (30 minutes)		
	50 (1 day)		
	40 (1 year)		
Common zone	100 (30 minutes)		
	50 (1 day)		
	40 (1 year)		
Industrial zone	200 (30 minutes)		
	100 (1 day)		
	80 (1 year)		

* maximum concentration not to be exceeded more than once per year.

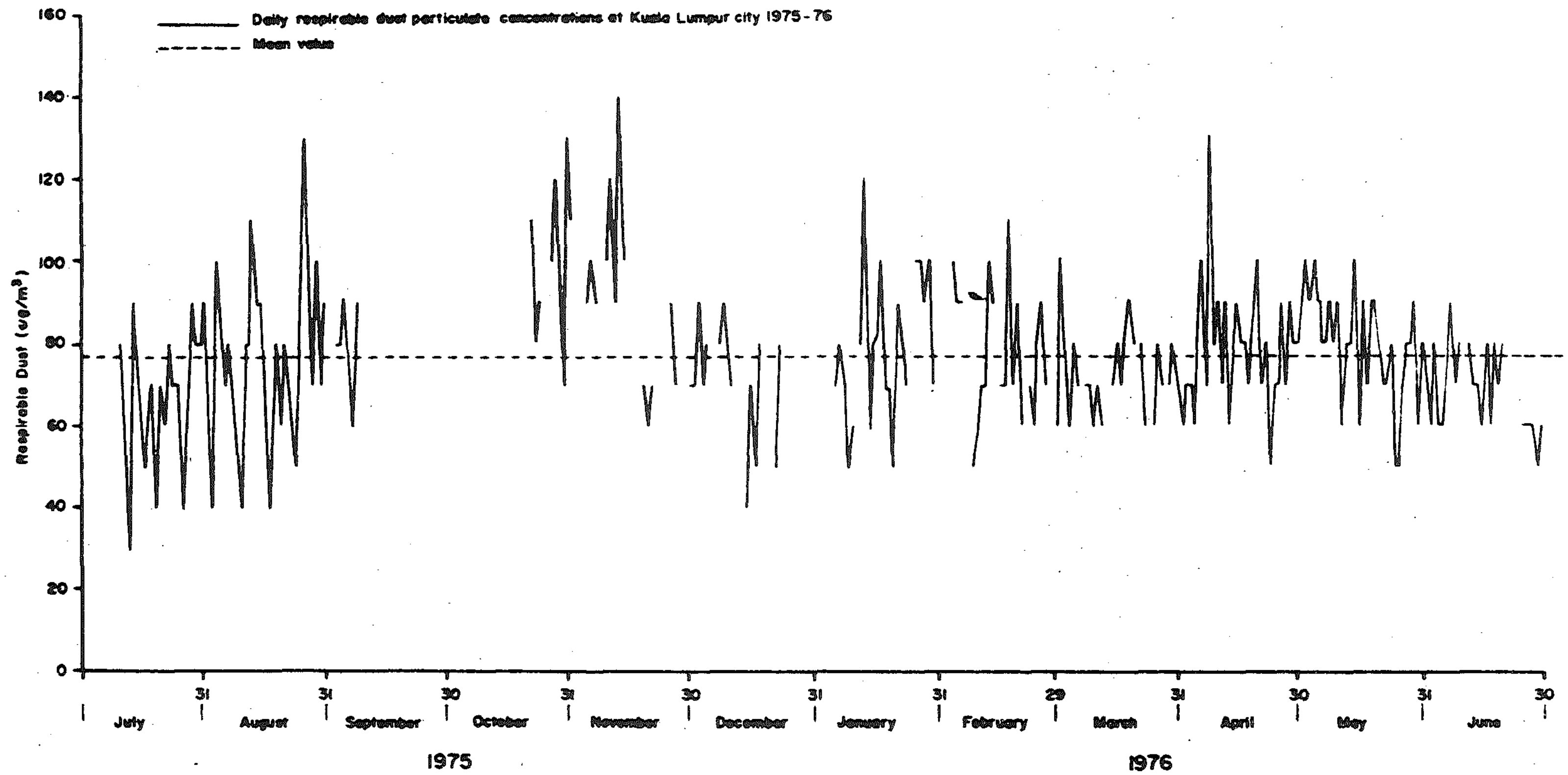


Figure 48: Daily concentration of respirable dust particulate at Kuala Lumpur City, 1975-76. Broken line indicates mean value

to results obtained in several mid-latitude cities (e.g. Bland, 1974; Kleinman et al, 1976; Tapper, 1976; Schwartz, 1975), marked seasonal variations and episodic type pollution occurrences are not evident (Figure 49). Although there is a high degree of daily variability, the respirable dust particulate concentrations generally remain within 40-120μg/m^3 range throughout the year. There also appears to be very little persistence in the daily concentration values. The auto-correlation coefficients generally show a rapid fall from 1.0 for a zero-lag to 0.22, 0.10, and -0.05 for a one-, two-, and three-day lag respectively. This is probably one reason why the air pollution problem in the study area has not been too apparent despite the relatively high pollution level particularly in the city area. This lack of seasonal variations and episodic type pollution occurrences may be attributed, at least in part, to the absence of any marked seasonal variations in the type and amount of energy use following the absence of any distinct cold and warm seasons as these are experienced in the mid-latitude regions, and the absence of very prolonged temperature inversions which very often accompany extreme pollution concentration occurrences in mid-latitude cities.

Samples for the different land uses within Kuala Lumpur - Petaling Jaya indicate that the highest mean value was recorded at an industrial site with 102μg/m^3, while the Lake Garden, a parkland area, recorded the lowest mean value with 25μg/m^3. The corresponding values for commercial and residential areas are shown in Table 40. An analysis of variance shows that the mean values are significantly different at the 0.001 level with an F-value of 94.8787. The t-tests performed on the mean values obtained from the Lake Garden, on the one hand, and those of the other areas indicate that these are generally significant at the 0.001 level (Table 41).

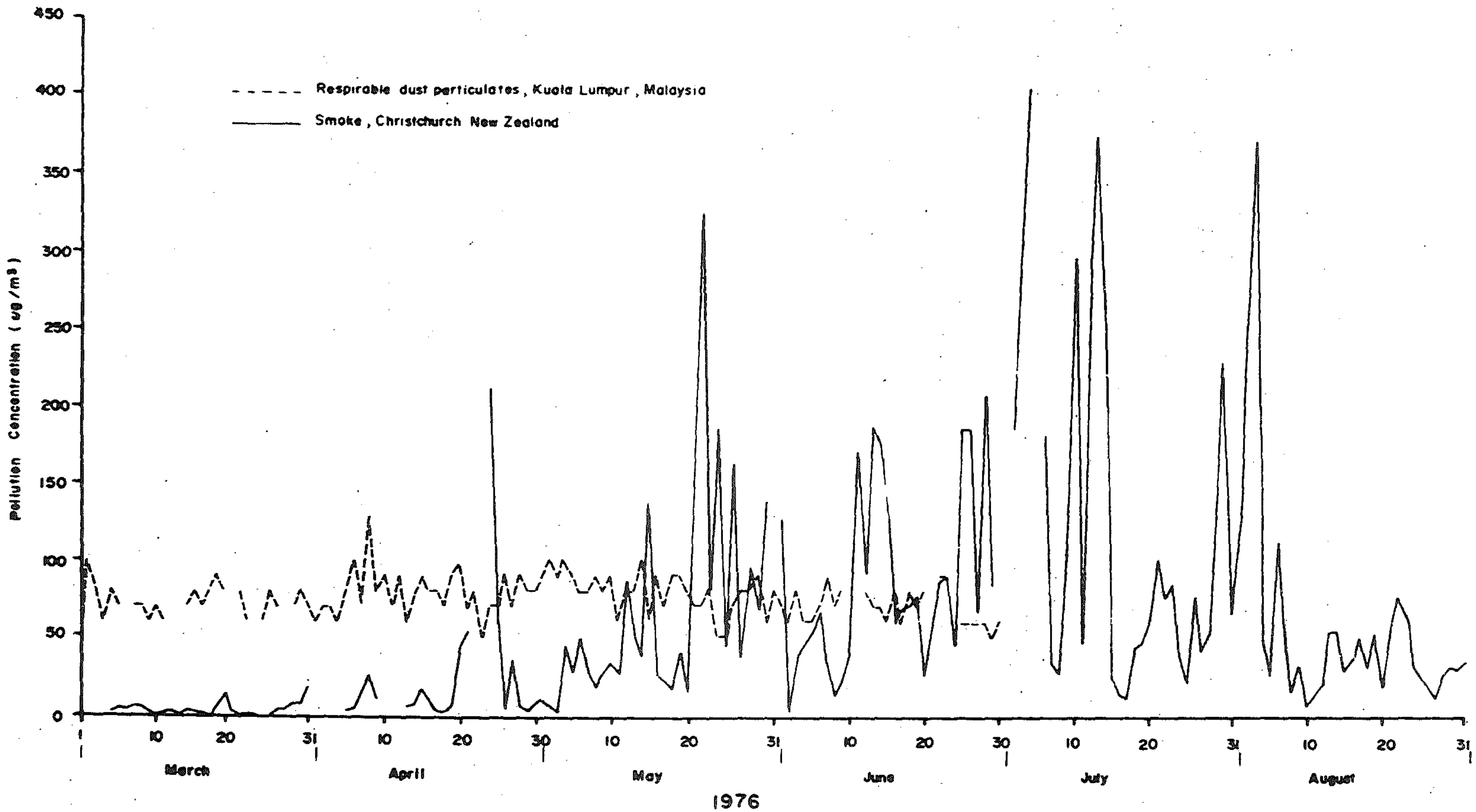


Figure 49: Respirable dust particulate at Kuala Lumpur and daily smoke in Christchurch during March-August, 1976

TABLE 40

Variation of Respirable Dust Particulate Concentration in the Kuala Lumpur-Petaling Jaya area

Landuse type	N	mean ($\mu g/m^3$)	median ($\mu g/m^3$)	Standard deviation ($\mu g/m^3$)	Coefficient of variation (%)	F- value	significance
commercial	51	76	80	17	22.50	94.8787	0.001 level
industrial	25	102	100	33	31.96		
residential	25	34	30	12	35.29		
park	27	25	20	8	33.20		

(source: Field Measurements)

TABLE 41

t-values for the different landuse types in the Kuala Lumpur-Petaling Jaya area

	commercial	industrial	residential
commercial	-	-	-
industrial	3.70	-	-
residential	12.43	9.80	-
park	17.77	3.63	3.13*

* significant at 0.01 level. The rest are significant at 0.001 level.

(source: Field Measurements)

There has been no comparable study carried out elsewhere with regard to respirable dust particulates and landuse types. Nevertheless the results for Kuala Lumpur - Petaling Jaya generally confirmed those obtained for similar studies with respect to suspended particulates in the atmosphere. Demuynck & Dams (1975), in a study of airborne particulate matter at 14 residential, industrial and rural locations in Belgium, showed that, on average, the industrial locations recorded the highest concentration with 118$\mu g/m^3$ followed by residential locations with 103$\mu g/m^3$; rural locations recorded the lowest with 60$\mu g/m^3$. The percentage frequency of 'polluted', 'normal' and 'clean' air over a variety of land uses has also been studied by Bach (1972b) in Cincinnati. His results showed that the industrial site experienced almost exclusively 'polluted' air, whereas the city park had predominantly 'clean' air over the same summer period. It was also noted that the concentrations over the industrial site on a 'clean' day were as high as those over the park and residential sites on a 'polluted' day. Unfortunately, absolute figures of pollution concentrations were not available for direct comparisons. The ability of green areas to filter out dust, soot and fly ash from the atmosphere has long been known and several examples have already been noted in connection with the dustfall in and around Batu Caves.

Table 42 gives the variation with height of respirable dust particulate concentration over the centre of Kuala Lumpur. It can be observed that there is a general decrease in values with height; the percentage attenuation between the 1.22-m (4-foot) and the 50.29-m (165-foot) levels are respectively 50.62 and 59.62 for the morning (0730-1630 hours L.T.) and afternoon (1630-0130 hours L.T.) readings. In both cases an analysis of variance indicates that the values are significantly different at the 0.001 level with F-values of 57.5000 and 33.5714 respectively. It is further noted that compared with the morning readings, those of the afternoon showed a marked decrease in mean concentration values with height, particularly between the 1.22-m (4-foot) and the 9.14-m (30-foot) levels. The generally less turbulent condition and hence less vertical mixing between about 1800 hours (L.T.) and 0130 hours (L.T.) could be one explanation for the relatively greater attenuation with height during the afternoon observation. In contrast, the atmospheric condition covering the morning observation period is completely different particularly between about 1000 hours (L.T.) and 1630 hours (L.T.) when turbulence is at its greatest (see Chapter 2). Under this situation, vertical mixing will be enhanced resulting in a reduced attenuation with height. The generally low mean values in the afternoon readings reflect the decreasing vehicular traffic and human

TABLE 42

Variation with Height of Respirable Dust Particulates in Central Kuala Lumpur

altitude	morning (0730-1630 hours L.T.)						afternoon (1630-0130 hours L.T.)					
	N	mean ($\mu g/m^3$)	median ($\mu g/m^3$)	standard deviation ($\mu g/m^3$)	coefficient of variation (%)	F-value	N	mean ($\mu g/m^3$)	median ($\mu g/m^3$)	standard deviation ($\mu g/m^3$)	coefficient of variation (%)	F-value
4feet (1.22m)	14	81	80	22	27.16	57.5000 (significant at 0.001 level)	14	52	50	17	32.69	33.5714 (significa at 0.001 leve
30feet (9.14m)	37	74	80	15	20.27		37	37	30	11	29.73	
165feet (50.29m)	28	40	40	11	27.50		28	21	20	9	42.86	

(source: Field Measurements)

activities in the city centre after about 1700 hours (L.T.). Offices in the city area normally close at 1600 or 1630 hours (L.T.).

Although comparable studies of vertical variation of respirable dust particulates are not available for other areas within or outside the tropics, the results obtained in the present study are generally consistent with those of similar investigations on total suspended particulates. Bach (1971a) showed that suspended particulates decreased by about 20 percent from 179$\mu g/m^3$ to 144$\mu g/m^3$ within 50m (165 feet) of the city atmosphere. McCormick & Baulch (1962) summarized turbidity data from helicopter soundings and observations from buildings in Cincinnati. Their results indicate that the lowest 600m of air over the industrial location contribute 70 percent to the total aerosol attenuation. Bach (1971b) showed that for the same depth of atmosphere 83 percent of the aerosol attenuation occurred. In both cases, no absolute figures for mass concentrations of aerosols were given and hence comparison on this basis is not possible. There was however a slight variation in the results from Calgary, Canada reported by Nkemdirim et al (1975). Their results indicate that there is a stratification of COH in the urban atmosphere with the biggest concentration of 0.15 centred around the 50-m level. The area closest to the ground has consistently the smallest COH level (0.11). The existence of a semi-permanent elevated layer of pollutants has been attributed to the 'downwash' effect due to a collapse of the upper layers of the urban heat island and the redistribution of lower level pollutants mainly due to regional wind and the physical setting of Calgary.

4.4.3 Weekly Cycle of Respirable Dust Particulates

The weekly cycle of pollution has been studied in many cities. In Leicester, England, the ratio of both the smoke and SO_2 content of atmosphere on Sundays and bank holidays compared to other days averaged between 0.55 and 0.87, depending on the season (Department of Scientific and Industrial Research, 1945). A year-round reduction in smoke on both Saturday and Sunday has been observed in Ottawa and Vancouver (Munn & Ross, 1961; Munn, 1961). In Paris, a significant reduction in smoke occurs on Saturday, with a further reduction on Sunday (Grisollett & Pelletier, 1957). A comparison of mean soiling index for the different days of the week at three stations in Montreal shows a reduction on Sunday amounting to between 17 and 23 percent of the mean weekday value, and a slightly smaller reduction on Saturday (Summers, 1966). For all the three Montreal stations reported by Summers (1966) the differences among weekdays is statistically insignificant, but the reduction on both Saturday and Sunday is significant at the 97 percent, or greater, confidence level. It is also noted that there is some tendency for highest readings to occur at the beginning of the week (Monday or Tuesday) and again on Friday.

The mean and median values of respirable dust particulate loadings for each day of the week as recorded in the inner city of Kuala Lumpur are given in Table 43. In broad agreement with studies of weekly cycle of pollution in other areas, values are observed to be lowest on Sundays, intermediate on Saturdays, and highest on weekdays. No tendency for higher values at the beginning of the week and Friday as reported by Summers (1966, p.433) was observed. A reduction on Sunday amounting to 20.25 percent of the mean weekday value is noted with a corresponding figure of 8.86 percent for Saturday. Unlike most western countries, Saturday is a 'half'-working day in Kuala Lumpur - Petaling Jaya. Offices normally close at 1245 hours (L.T.). The differences among weekdays (Mondays -

TABLE 43

Mean and Median Particulate Loadings for Respirable Dust by Day of the Week in Central Kuala Lumpur

	N	mean ($\mu g/m^3$)	median ($\mu g/m^3$)	standard deviation ($\mu g/m^3$)	coefficient of variation (%)	F-value	t-value
Monday	39	77	80	16	20.77		
Tuesday	39	80	75	20	25.00		
Wednesday	43	80	80	14	17.50		
Thursday	39	79	80	17	21.51	-	-
Friday	38	80	80	16	20.00		
Saturday	30	72	70	15	20.83		
Sunday	22	63	65	19	30.15		
Sunday *vs* weekdays	-	-	-	-	-	-	4.7404 (sig. at 0.001 level)
Sundays & Saturdays *vs* weekdays	-	-	-	-	-	-	4.1045 (sig. at 0.001 level)
Among weekdays (Monday-Saturday)	-	-	-	-	-	5.3389 (sig. at 0.001 level)	-
Among weekdays (Monday-Friday)	-	-	-	-	-	0.2118 (not sig. at 0.001 level)	-

(source: Field Measurements)

Fridays inclusive) are statistically insignificant, the F-value being 0.2118. However, if Saturdays are included in the calculation for weekdays, the differences are found to be significant at the 0.001 level, the F-value being 5.3389. The reduction on both Saturday and Sunday is also statistically significant at the 0.001 level. It thus appears that in Kuala Lumpur, the shutting down of offices and commercial activities does lead to a significant reduction in downtown respirable dust particulates over the weekend particularly on Sunday. The reduction is relatively smaller however on Saturday as it is a 'half'-working day. Furthermore shops in the city area remain open as usual.

4.4.4 Possible Weather Influence on Respirable Dust Particulates

Meteorological factors have an important effect on the amount of pollution in the atmosphere. The general way in which these are related has been noted in Chapter 1. The implications of Kuala Lumpur - Petaling Jaya climate for air pollution potential have been presented in Chapter 2. It was noted that wind speed and direction, precipitation scavenging and atmospheric ventilation are among the most important factors in determining the ability of the atmosphere to disperse air pollution. This section examines whether respirable dust particulate concentrations can be explained in terms of these factors.

(a) Wind Speed and Direction: As measurements are not available in the city area, wind data from Subang Airport have been used to examine the possible influence of wind factors upon respirable dust particulates in the city. Although these are not indicative of the urban flow particularly when the regional pressure gradient is weak, the airport data would at least give some idea of the general wind condition in the Kuala Lumpur - Petaling Jaya area.

Figure 50 shows the relation between mean and median concentrations of respirable dust particulates and mean wind speed during the sampling period using all available observations excluding Sundays. Above about 3.0 ms^{-1} (5.82 knots), there appears to be a linear decrease of concentration with increasing winds, as would be expected and is assumed in most diffusion models: the pollution is stretched in the forward direction, the volume of air available for dilution increasing with increasing wind speeds. The correlation coefficient however is low, r-value being -0.1273, and statistically insignificant at the 0.05 level. No well-defined pattern is observed with winds less than about 2.6 ms^{-1} (5.04 knots). It does appear however that with wind class 1.6 - 2.0 ms^{-1} (3.10 - 3.88 knots), the degree of turbulence created may be such that it induces just enough mixing to result in high concentration values. A secondary peak in the 2.6 - 3.0 ms^{-1} (5.04 - 5.82 knots) wind class is somewhat difficult to understand but may be due to combinations of unlike members being included in different subsets. The day-of-the-week and wind direction distributions, for example, might be significantly different with low wind speeds than they are with high speeds. These possibilities have been examined insofar as practical but due to the limited number of samples available, the analysis has not been exhaustive. Alternatively, the secondary peak in the 2.6 - 3.0 ms^{-1} (5.04 - 5.82 knots) wind class may be due to either (a) reentrainment of surface dust in relatively strong winds, or (b) the possible effect of a distant tall chimney. It is interesting to note that during the period of field observation at least two major building construction activities were in progress

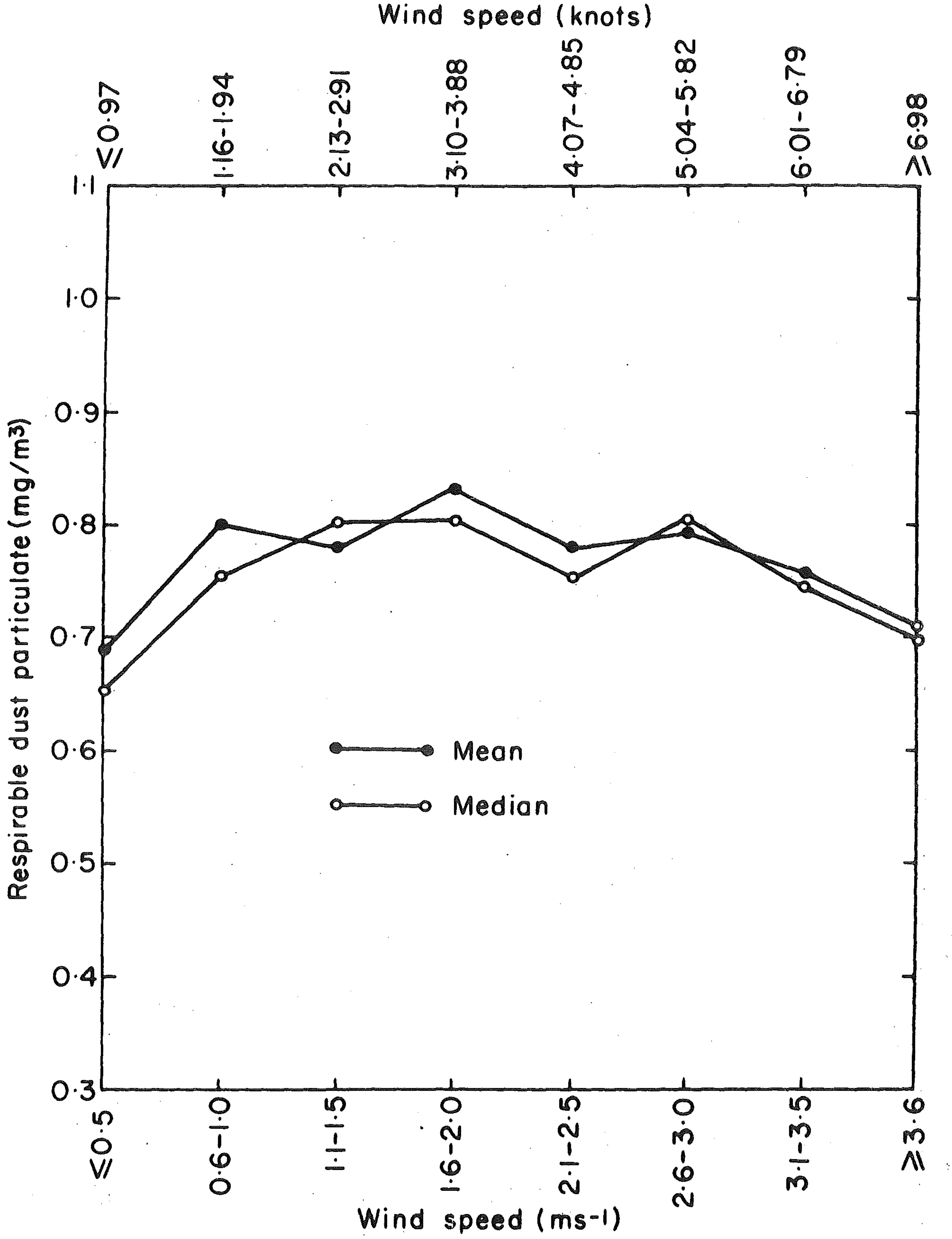


Figure 50: Relationships between mean and median concentrations of respirable dust particulates and mean wind speed during sampling period excluding Sundays

within a radius of 300 metres (990 feet) from the observation site in the city centre. Similar curves were also observed by Munn (1973b) in Toronto Canada, and by Bezuglaya & Sonkin (1971) in Moscow and Leningrad: they attribute the strong-wind peaks to tall chimneys.

A linear correlation between respirable dust particulates and average daily wind speed $\geqslant 1.1 \text{ ms}^{-1}$ ($\geqslant 2.13$ knots) at Subang Airport yields a better relationship, r-value being -0.2358, and is statistically significant at the 0.05 level with standard error of estimate (S.E.E.) equals $\pm$ 17.5057. However, this is still lower than figures obtained for mid-latitude cities (e.g. Owens & Tapper, 1977; Turner, 1961).

An attempt to see the effect of wind direction on respirable dust particulate concentration in this study suffers from a lack of wind data for certain directions, and necessary overgeneralization due to lack of wind measurements in the city area. Further, sampling of respirable dusts on a daily basis (in the present case 9 hours) is not ideal for meteorological interpretation. If a sample contains, for example, four hours of west winds, four hours of east winds, and one hour of north winds, there is difficulty in the meteorological interpretation of average concentration of particulates. In the present study, a modified version of the procedure due to Stewart & Matheson (1968) and Munn <u>et al</u> (1969) has been adopted. In the procedure only those subsets of days for which the wind direction remained within particular sectors for at least 40 percent of the time during the sampling periods were considered. This limitation introduces into this analysis a bias towards higher wind speeds since such directional constancy is usually associated with stronger winds. Similar problems were discussed by Rouse & McCutcheon (1970).

Figure 51 presents mean and median values of respirable dust particulate concentrations for eight wind directions in the central city of Kuala Lumpur. The corresponding values for calm period (not shown in the diagram) are 72 and 70$\mu g/m^3$ respectively. With the exception of NE winds for which no directional constancy of over 40 percent was observed, there does not appear to be any particular wind direction which may be associated with any particular air quality type. There is however a slight tendency for winds from the westerly direction to be associated with somewhat poorer air quality compared with those from other directions. This could probably be attributed to the prevailing westerly winds blowing over industrial sectors and areas with heavy traffic density to the west of the recording site.

(b) Precipitation Scavenging: A simple linear correlation between precipitation amount and respirable dust particulate concentration performed on all individual samples over the observation period indicates poor negative relationship, the r-value being only -0.041. Subsequently 'no-precipitation' and 'precipitation' groups were distinguished and a t-test was performed to see if significant difference could be found between the two groups. The resulting t-value was low however and not statistically significant at the 0.05 level. Further tests show that a significant difference was found between group of days with precipitation > 2.54mm (> 0.10 inch) and the rest of days, the t-value being 1.7391 and significant at the 0.05 level.

A correlation between dust particulate concentrations and daily precipitation amount ≤ 2.54mm (≤ 0.10 inch) still shows poor results although the tendency is towards an inverse relationship between the two variables: respirable dust particulate concentration

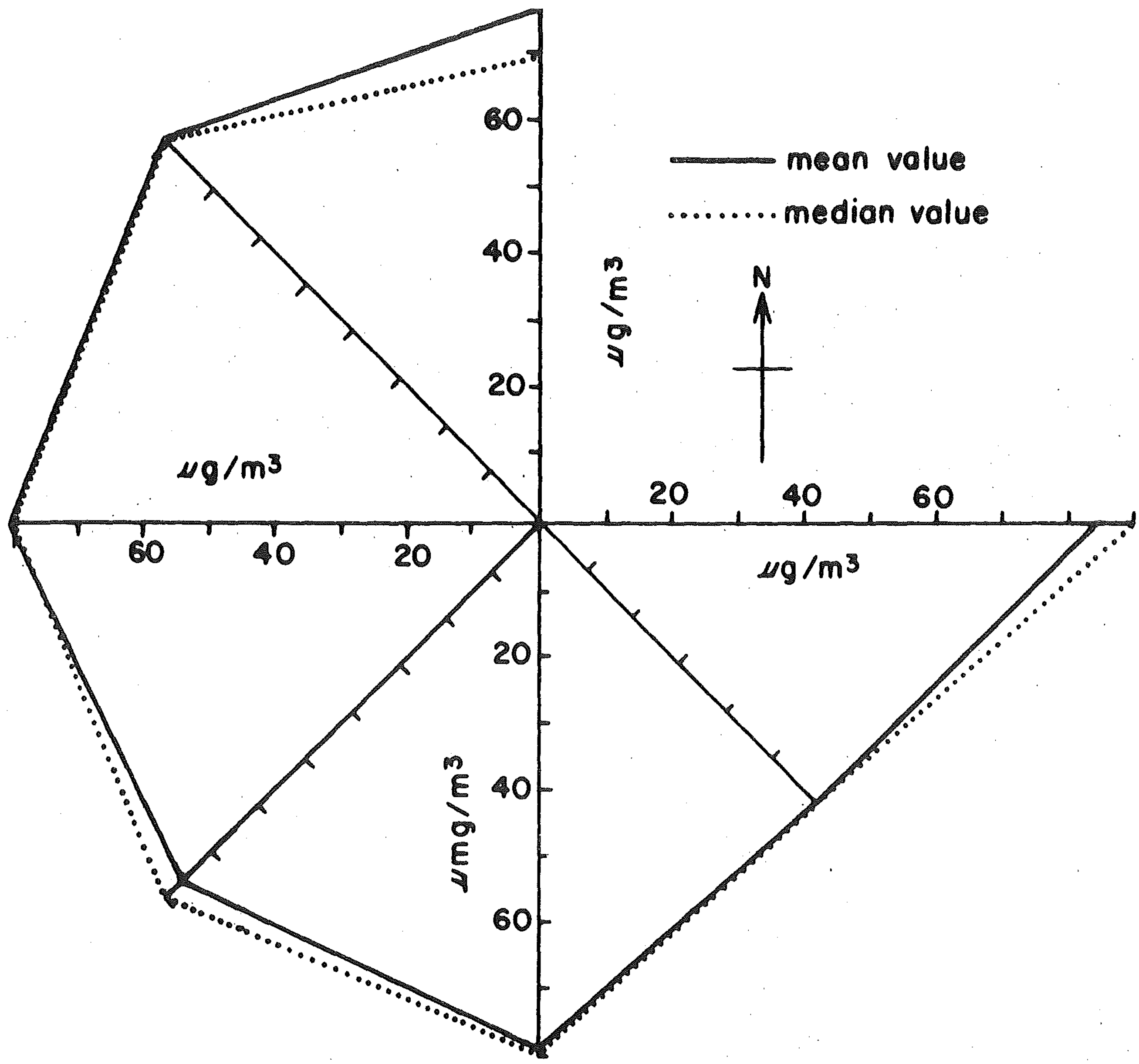


Figure 51: Relationships between respirable dust particulates and wind direction

decreases with increasing precipitation amount.

With precipitation amount greater than 2.54mm (0.10 inch), the correlation coefficient (r) improves to 0.6231 with standard error of estimate (S.E.E.) equals $\pm$ 12.3006, and is significant at the 0.01 level. Unlike that of precipitation amount $\leq$ 2.54mm ($\leq$ 0.10 inch), the relationship is positive. Although comparable studies of respirable dust particulates are not readily available, this is somewhat contrary to previous findings with regard to suspended particulate pollution generally. Dickson (1961), for example, reports an r-value of -0.38 between precipitation and particulate matter in Nashville, Tennessee while Greenfield (1957) shows how a uniform rainfall of 1.0mm (0.04 inch) per hour over a 15-minute period can scavenge 28 percent of the 10μm particulates from a volume of air through which the rain passed. Although no clear explanation for this apparent anomaly may be offered at this stage, one possibility would be that while particulate pollution may be reduced through washout process, particulates are, at the same time, also produced (perhaps at even a greater rate) following slow-moving motor vehicles and traffic jams which generally occur in the streets near the recording site when it rains. Further, as a large percentage of dust penetration through the filter disc is well below 5.0μm in diameter (Figure 47), washout process may not be very effective. It was noted earlier in Chapter 1 that although available evidence is conflicting, very small (< 1.0μm diameter) pollutant particles are believed to move out of the way of the scavenger. Bach (1972a, p.21) indicates that for particles of 2.0μm and smaller in diameter the scavenging through precipitation becomes insignificant. Thus while the effect of washout process upon the 'respirable fraction' of the suspended dust particulates is not very efficient, a steady supply of dust particulates becomes available at the recording site following slow-moving traffic and congestion in the nearby streets when it rains. Further, the humid atmosphere which occurs following rainfall, and the generally low wind speed induce poor pollution dispersion resulting in an increase in respirable dust concentration at the recording site.

(c) Afternoon Mixing Depth and Atmospheric Ventilation: Maximum mixing depth (in the present case, the afternoon mixing depth) as an indicator of the atmosphere's ability to dilute pollutant concentration has been noted. Summers (1966) notes the relationship between daily suspended particulate concentration and mixing depth values in Montreal although no correlation was attempted. He suggests that the occurrence of morning peak in soiling index can be explained by the continuous night time 'fumigation' process over large urban area. In the present study, this type of analysis has not been possible as respirable dust particulate concentrations are observed not on an hourly but a daily basis.

A linear correlation between individual daily samples of respirable dust particulate and afternoon mixing depth yields only a poor negative relationship, the r-value being -0.059. As respirable dust particulate concentrations for days having more than 2.54mm (0.10 inch) of precipitation amount have been found to be significantly different from those having 2.54mm (0.10 inch) and less, afternoon mixing depth and respirable dust particulate concentration values are separated into two groups with linear correlation performed on each.

No significant relationship however was found between respirable dust particulates and afternoon mixing depth although there appears to be a tendency towards an inverse relationship between the two variables: respirable dust concentration decreases with increasing afternoon mixing depth.

It thus appears that the influence of weather factors upon respirable dust particulates in the Kuala Lumpur - Petaling Jaya area is largely inconclusive. This is contrary to mid-latitude studies which generally do demonstrate significant correlation between pollution and weather (e.g. Bringfelt, 1971; Turner, 1961; Owens & Tapper, 1977). However, it must be noted that the analysis in the present case has been somewhat limited because of lack of stations within Kuala Lumpur - Petaling Jaya and the need for smaller time interval of sampling.

While the effect of meteorological factors upon respirable dust particulates in the present study has not been well established, the factor of local relief may be important in determining pollution levels (e.g. Tyson, 1963; Garnett, 1967; Shenfeld, 1970b). During the day it is doubtful whether in the unstable conditions ridges have any marked mechanical effect compared with the thermal eddies of large vertical extent which quickly disperse materials released in valleys or hollows. At night, however, vertical flow within a valley is dominated by the circulations generated by the cooling of the valley slopes and virtually isolated from the general air flow above the ridges. Under stagnant macroclimatic conditions, the confined circulations within valleys can have serious consequences, producing abnormally high pollution levels in some cases. Although the possible effect of topography upon pollution levels has not been explored in the present study, the basin-like terrain in which Kuala Lumpur - Petaling Jaya is located (Figure 3) and the prevalence of stagnant macroclimatic conditions particularly at night and during early part of the morning (Figures 10 and 11) have been noted. This together with the changing patterns of human activities (in terms of automobile and industrial emissions) may in fact contribute significantly to the daily levels of pollution in Kuala Lumpur - Petaling Jaya.

4.5 Summary

This Chapter has presented three case studies for which air pollution measurements are available. The main conclusions and observations that arise from the study are as follows:-

1. The dustfall in and around Batu Caves has now become a great concern to the nearby residents. On the average, the mean monthly dustfall for the area within a 3.2-km (2-mile) radius of Batu Caves was 12 tonnes/km^2/month (30.2 tons/$mile^2$/month) which far exceeded the standard recommended for residential and light industrial areas. Stations 1, 4, and 6 already exceeded even the standard recommended for heavy industrial regions.

2. It was observed that vegetation in the Batu Caves Estate, the orientation of the limestone outcrop in providing physical barrier, and possibly the prevailing westerly winds all contributed to the present distribution pattern of dustfall within and around the area. Linear correlation between dustfall and precipitation amount suggests only a poor relationship. The positive correlation between these two variables may probably be due to the generally more stable atmospheric condition and hence less pollution dispersion when rain occurs.

3. Although the distribution pattern of dustfall generally suggests a single source hypothesis, other sources of pollution such

as sawmills and fine sand from mining areas immediately outside the gauged area may also contribute to the present patterns. However, their exact proportion is not known.

4. The sulphur dioxide levels in the industrial section of Petaling Jaya are generally low. The value recorded at the Malayan Acid Works, however, has already exceeded the accepted levels for human health and vegetation. For the three-year period, the monthly value recorded at the Malayan Acid Works range from 0.04 to 0.09 p.p.m.

5. The distribution patterns of sulphur dioxide suggest that they were greatly influenced by the prevailing winds from the westerly quarter. A statistically significant correlation was also found between average values of precipitation amount and SO_2 for the years 1972-75 over the 12-month period.

6. Comparison with average total particulate concentration in mid-latitude cities shows that problems of dust particulates can be quite serious. The concentration values however vary greatly within the study area: the highest mean value was recorded at an industrial site with $102 \mu g/m^3$ while the Lake Garden, a parkland area, recorded the lowest value with $25 \mu g/m^3$. Mean concentration values also vary with height, the percentage attenuation between 1.22-m (4-foot) and 50.29-m (165-foot) levels being between 50 to 60 percent. Contrary to results obtained in mid-latitude cities, marked seasonal variations or episodic type pollution occurrences are non-existent.

7. In broad agreement with studies of weekly cycle of pollution in other areas, mean values of respirable dust particulate concentrations are observed to be lowest on Sundays, intermediate on Saturdays and highest on weekdays. A reduction on Sunday amounting to 20.25 percent of the mean weekday value is noted.

8. The influence of weather factors upon respirable dust particulates is largely inconclusive. However, it must be recognized that the analysis in the present study has been somewhat limited due to lack of stations within Kuala Lumpur - Petaling Jaya and the need for smaller time interval of sampling.

CHAPTER FIVE

POSSIBLE EFFECTS OF AIR POLLUTION AND URBANIZATION ON CLIMATIC PARAMETERS

5.1 Introduction

The discussions in previous chapters have been generally concerned with aspects of air pollution concentrations and the extent to which these are related to weather factors. Studies from mid-latitude areas, however, indicate that there is a two-way relationship between meteorological processes and atmospheric pollution. Weather and climate are also influenced by the presence of pollution in the atmosphere, although in some cases the effects have not yet been well established. The aim of this Chapter is to examine the extent to which air pollution in Kuala Lumpur - Petaling Jaya have affected climatic parameters. However, as it is difficult to isolate pollution effect from the much stronger controls of synoptic climatology and urban morphology, the possible influence of both pollution and urbanization upon climatic parameters is considered together.

5.2 Data and Their Limitations

It has been noted in Chapter 1 that the climate data for the present study come from many sources. One major problem which is encountered in the analysis of this information is the different time scale for which the data are available. The station at Weld Reservoir, for example, began in January, 1975 while records at Subang and the University of Malaya are available from 1966. The records at Petaling Jaya began in 1971. In the present study, periods of records used in the various analyses were allowed to vary in so far as possible so that all reliable records would be used in each specific analysis, rather than discard useful data to keep all analyses on the same time basis.

The differences in the site characteristics of the various stations posed another problem particularly when data from one station have to be compared with those of another. Weld Reservoir, for example, is located on a hill and is 65.8m (217 feet) above mean sea level. It is thus difficult to assume that the climate data recorded here are truly representative of the city condition. In most instances, therefore, it is more meaningful to compare Subang and Petaling Jaya (which are relatively more similar in term of sites) even though Petaling Jaya is only 'suburban' in character. For certain climatic elements, however, only Weld Reservoir and Subang may be compared. When this occurs, extreme caution has to be exercised in interpretation.

The interpretation of data for the University of Malaya has similar problems particularly when this station is to be compared with Subang or Petaling Jaya. The University of Malaya station is located on top of a hill 103m (340 feet) above mean sea level. The extent of level ground at the top is small and the hill slopes down rather steeply. Thus not only the movement of air is highly influenced by the local topography, rainfall and temperatures are also affected by the open exposure.

The limited number of stations available within and around the study area posed another problem. The differences in site characteristics and time scale for which the data are available have severely limited their usefulness. An attempt has therefore been made to supplement this lack of data by means of mobile traverses particularly in the case of temperature and humidity.

Defective records due to faulty instruments particularly at Weld Reservoir represent another problem. To a large extent this was unavoidable as most of the instruments lacked strong stands. The grass-covered concrete dome of the reservoir on which the instruments were located made digging virtually inadvisable. Only wooden supports were used to keep the stands firm. In all cases, however, data for the missing days at Weld Reservoir were estimated using regression equations. Details of these are given in Appendix E.

In the case of rainfall analyses, the primary source of data used was the precipitation records maintained by the Drainage and Irrigation Department (D.I.D.). These were supplemented by records from three other stations operated since the early sixties by the Malaysian Meteorological Service (Subang and Petaling Jaya) and the University of Malaya (Figures 8 & 52). As in previous cases, periods of records used in the various analyses were allowed to vary in so far as possible so that all reliable records would be utilized in each specific analysis. However, even with this allowance, the study still lacks sufficiently long records and adequate station density to determine satisfactorily the statistical significance of apparent abnormalities of the precipitation distribution in urban areas.

One major problem in an attempt to assess the possible urban-industrial effects upon precipitation was the reliability of available records within and around the study area. Limitations of this nature have been discussed in detail by Lockwood (1967) and more recently by Chia (1973). However, by using only the data after 1953 it was hoped that likely observational errors would be minimized.

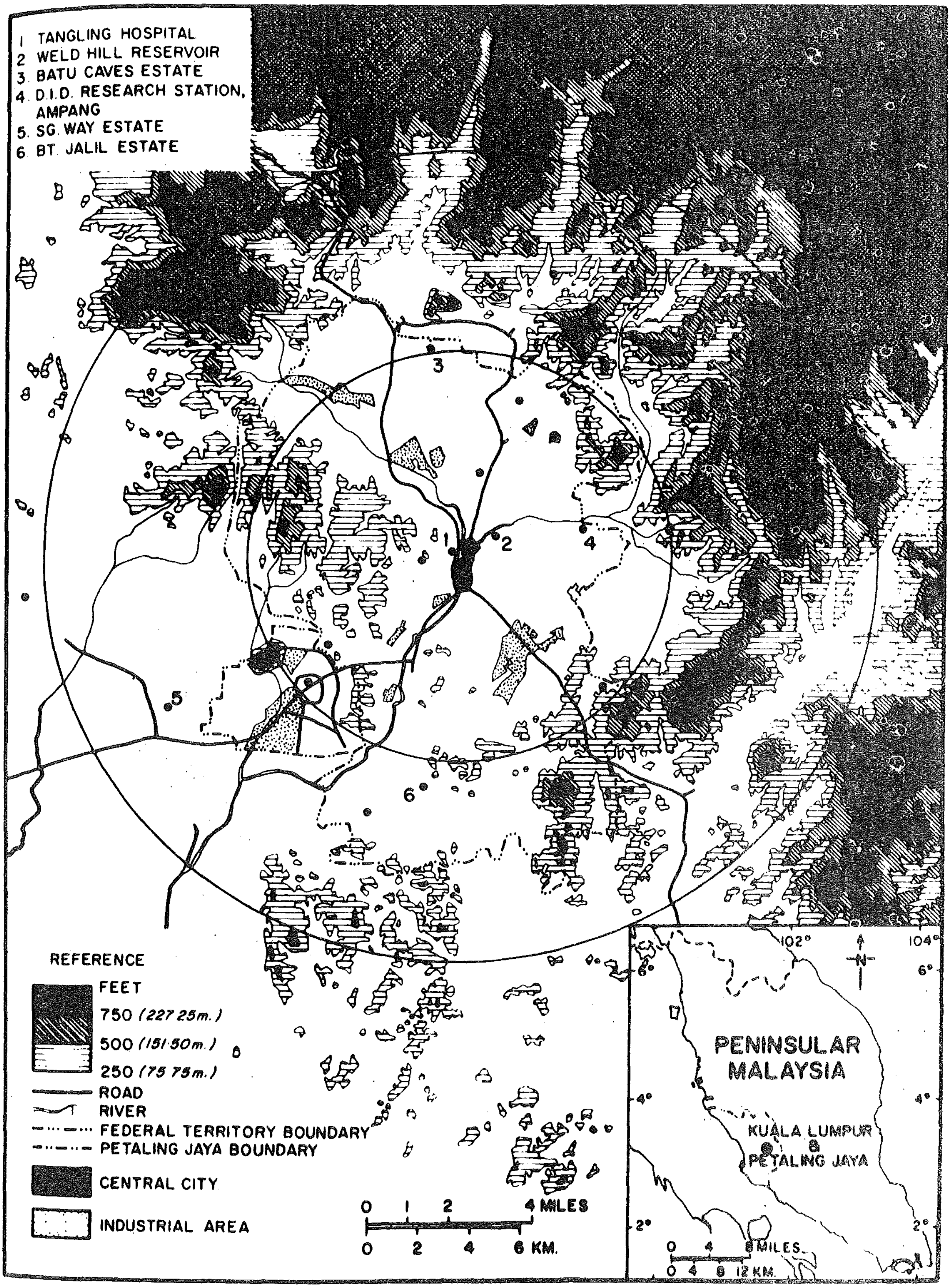


Figure 52: Location of rainfall stations used in the analysis. Stippled areas denote location of major industrial activities. The Kuala Lumpur central city is marked black

Chia (1973, p.5) observed that inspection of some of the recent rainfall data showed a definite improvement in quality.

5.3 Winds

The flow of wind over urban areas and the way in which this differs from that over the surrounding countryside has been noted in Chapter 1. It was shown that with strong regional wind, the city tends to modify the flow while with weak wind it may generate its own circulation system.

Chandler (1965) working in the London area showed that with strong winds urban speeds are decreased, but with light winds urban speeds are higher. The critical wind speed determining the effect showed a seasonal range of 3.5 to 5.5 ms^{-1}. Bornstein et al (1972) show similar results for New York. Their critical wind speed was about 3.8 ms^{-1} below which they suggest the heat island pressure gradient induces accelerated flow, and above which it is decelerated due to greater surface roughness.

Constant volume (tetroon) balloons have been used to study the windfields over New York (Hass et al, 1967; Angell et al, 1968), Los Angeles (Angell et al, 1971; Angell et al, 1972), Columbus, Ohio (Angell et al, 1971) and Oklahoma City (Angell & Pack, 1972). The results consistently show a tendency to move towards anticyclonic turning over the central urban area (towards lower pressure), followed by a cyclonic recovery downwind of the city. The tetroons also indicate upward air motion over the city in both light and strong winds.

Urban wind profiles using conventional balloons are reported by Clarke (1969), McElroy (1971), Ackermann (1972) and Wuerch (1972).

In broad agreement with the tetroon studies, anticyclonic turning of the wind and urban deceleration were all noted.

The use of wind tunnels and scale models to simulate urban windfields has also been reported in the literature. Jones & Wilson (1968) show comparisons between full-scale and a 1:500 scale model of a limited urban area, and Davis (1968) and Davis & Pearson (1970) tested a 1:1000 model for Fort Wayne, Indiana at an open site and compared with full-scale tower measurements. Similar works have been undertaken by Cermak (1970), Chaudhry & Cermak (1971) and Sadeh et al (1971).

An analysis of average wind speed at Subang Airport and at Petaling Jaya, a suburban station, tends to confirm the results of Chandler (1965) for London and those of Bornstein et al (1972) for New York (Table 44). Over the year as a whole, night-time winds increase their speed as they move into the central areas, and the stronger day-time winds decrease in speed; the night-time increase being about twice the day-time decrease. This pattern is observed to be particularly evident during the southwest monsoon (June-September) when mean wind speeds during the day are relatively stronger. The explanation of this reversal of the urban influence lies mainly in the diurnal cycle of wind speeds and stability. By night winds at Subang are usually light and the air relatively stable. In consequence, there will be a steep vertical wind gradient with more slowly moving air near the ground. Above the city, increased mechanical turbulence will bring down faster-moving air and the mean near-surface wind speed will be increased. By day, wind speeds are stronger and the air less stable, and there will be much more vertical exchange of momentum so that wind speeds in Subang will be more uniform in the lowest layers. In this case,

TABLE 44

Average Wind Speed at Subang Airport and its excess over that at Petaling Jaya, 1971-75. Speeds are given in ms^{-1}

month	0100 hours (LST)		1500 hours (LST)	
	mean speed	excess speed	mean speed	excess speed
Jan	0.11	-0.21	2.11	-0.21
Feb	0.11	-0.11	2.17	-0.16
Mar	0.16	0.00	2.42	+0.05
Apr	0.11	-0.16	2.37	0.00
May	0.16	-0.26	2.89	-0.26
Jun	0.26	-0.05	3.25	+0.62
Jul	0.16	-0.21	3.56	+0.62
Aug	0.36	+0.05	3.30	+0.50
Sep	0.21	-0.31	3.30	+0.46
Oct	0.26	-0.05	2.89	-0.36
Nov	0.21	-0.11	2.63	-0.31
Dec	0.05	-0.11	1.75	-0.31
Year	0.16	-0.11	2.73	+0.05

(source: Malaysian Meteorological Service)

the reduction of near-surface winds by frictional drag with the buildings of central and other parts of Kuala Lumpur - Petaling Jaya is more important than any small influx of faster-moving air from above. Air movements resulting from contrasted temperatures within and about the city area also play their part and help to explain some features of the seasonal fluxes in this basic pattern.

Figures 53 and 54 show the excess of wind speed at Subang Airport over that of Petaling Jaya for each day of the five years, 1971-75. Some interesting differences emerge. At times of light winds, speeds are increased in Petaling Jaya but with strong winds there is a decrease. The actual rate of increase and also the critical wind speeds which divide these two responses change with the time of day and with the seasons. This is also borne out by Table 45 where there is a tendency for greater wind speed in Petaling Jaya with relatively light winds and greater wind speeds in Subang when winds are strong.

Having in mind these features of the changing diurnal pattern of urban interference with the regional windfield, the longer period picture can now be better appreciated. One outstanding characteristic of wind speed in the Kuala Lumpur - Petaling Jaya built-up area compared with conditions outside is the relatively small number of calms and light airs (Tables 46 and 47). This is a feature displayed in all months and compares favourably with results obtained by Chandler (1965) in London. The small number of calms and light airs recorded at the University of Malaya station however is due not so much to urban effect but rather to the effects of altitude and exposure. This process, however, does not seem to operate with stronger winds. Here the picture is simpler, mean speeds decrease towards the city (Table 48). For winds of more

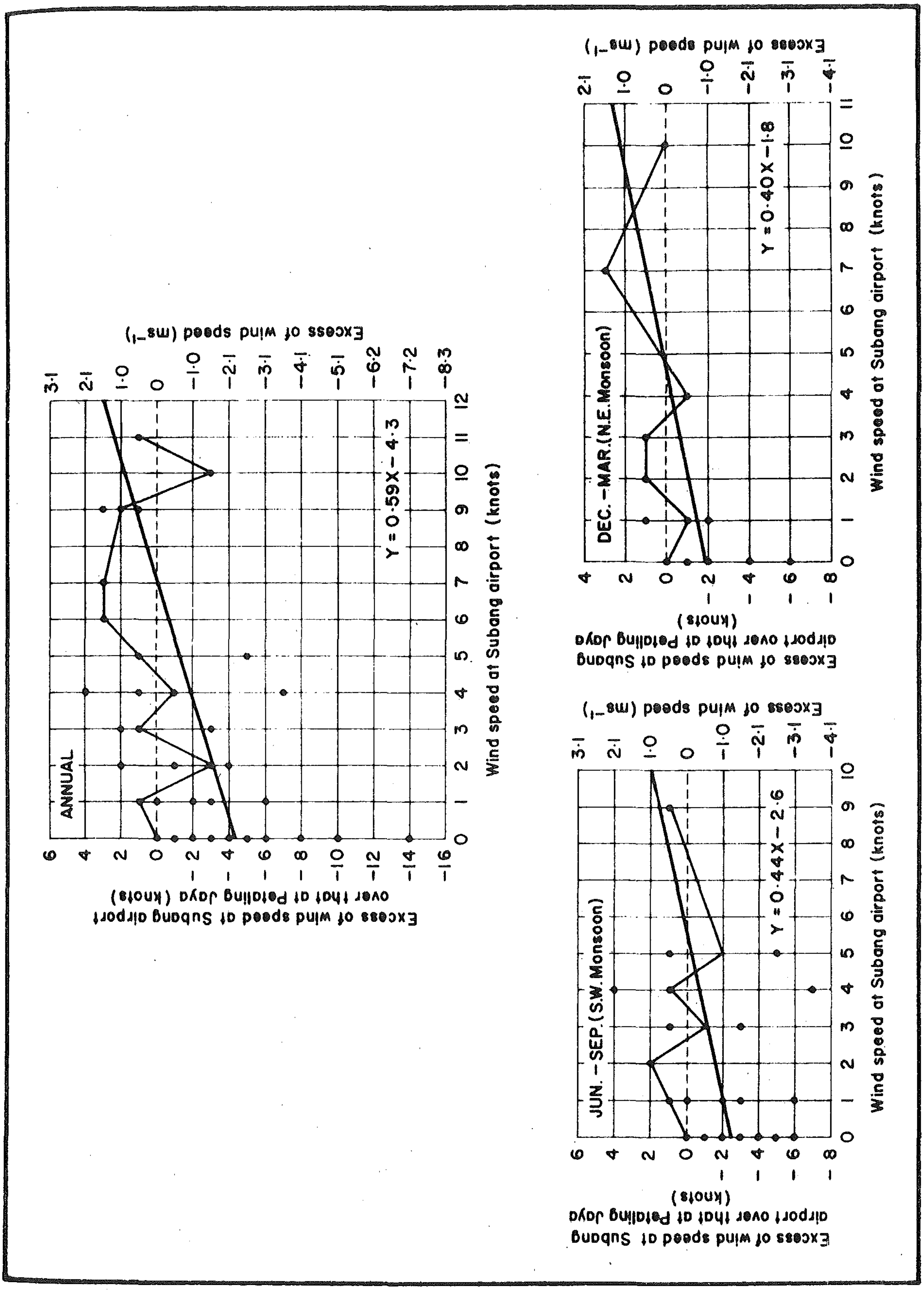


Figure 53: Excess of wind speed at Subang Airport over that at Petaling Jaya (Y), as a function of the wind speed at Subang Airport (X), 1971-75 taken at 0100 hours (L.S.T.). Thin line joins the median values of this difference and the thicker, straight line has been drawn by the method of least squares

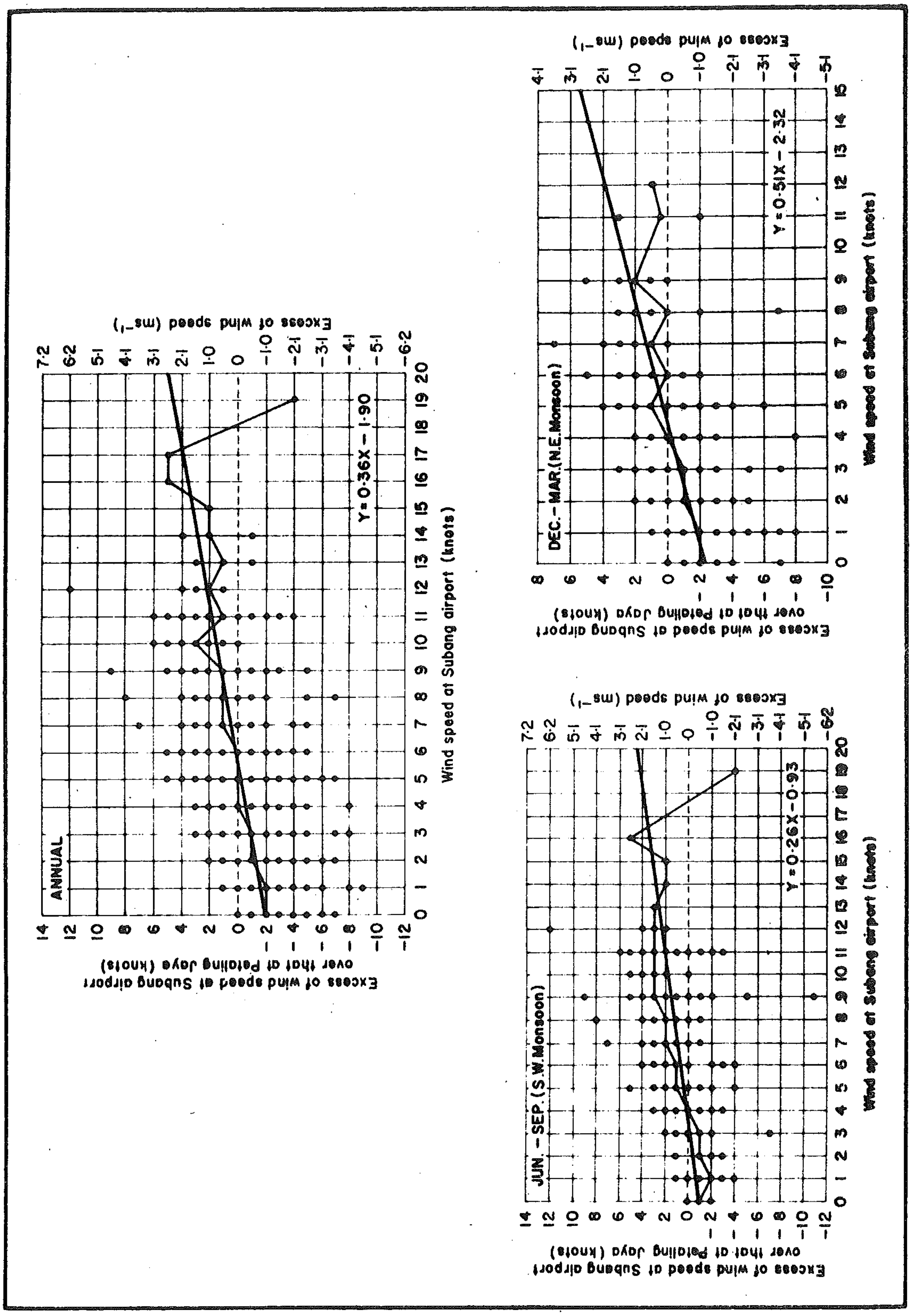


Figure 54: Excess of wind speed at Subang Airport over that at Petaling Jaya (Y), as a function of the wind speed at Subang Airport (X), 1971-75 taken at 1500 hours (L.S.T.). Thin line joins the median values of this difference and the thicker, straight line has been drawn by the method of least squares

TABLE 45

Average Hourly Wind Speed* at Subang (1966-75) and Petaling Jaya (1971-75). Figures are given in ms^{-1}

station	1	2	3	4	5	6	7	8	9	10	11	12
Subang (1966-75)	0.17	0.22	0.22	0.17	0.17	0.17	0.17	0.35	0.73	1.33	1.72	2.02
Petaling Jaya (1971-75)	0.26	0.26	0.30	0.26	0.30	0.30	0.30	0.39	0.64	1.03	1.46	1.80

station	13	14	15	16	17	18	19	20	21	22	23	24
Subang (1966-75)	2.36	2.71	2.75	2.45	1.80	0.77	0.30	0.22	0.13	0.13	0.13	0.17
Petaling Jaya (1971-75)	2.15	2.41	2.62	2.54	2.15	1.59	0.94	0.56	0.39	0.30	0.26	0.26

* corrected for effective heights

(source: Malaysian Meteorological Service)

TABLE 46

Percentage frequency of calm (wind less than 0.5ms^{-1}) for three stations in the Kuala Lumpur-Petaling Jaya area

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Subang (1966-75)	57.4	56.6	53.6	56.3	52.2	51.3	48.8	51.1	49.9	52.7	59.1	63.8	54.4
Petaling Jaya (1971-75)	43.0	46.1	44.3	42.8	43.2	45.2	39.9	42.0	39.3	46.5	42.1	51.0	43.8
University of Malaya (1966-75)	15.1	20.7	24.1	26.1	22.9	22.5	17.1	22.4	24.6	28.9	27.1	43.1	24.6

(source: Malaysian Meteorological Service)

TABLE 47

Percentage Frequency of Wind of 1.5 ms^{-1} and Below for Three Stations in the Kuala Lumpur-Petaling Jaya area

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Subang (1966-75)	80.9	79.4	75.6	79.8	74.0	71.8	68.6	70.8	71.7	74.5	79.3	85.2	75.9
Petaling Jaya (1971-75)	71.3	74.8	73.5	76.6	67.3	71.3	65.5	68.7	69.2	70.4	70.2	79.7	71.5
University of Malaya (1966-75)	42.4	52.8	54.0	55.7	54.8	55.5	49.4	55.1	57.5	55.1	56.9	67.4	54.7

(source: Malaysian Meteorological Service)

TABLE 48

Average Speed for Winds of More Than 1.5 ms^{-1} for Three Stations in Kuala Lumpur-Petaling Jaya.* Figures are given in ms^{-1}

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Subang (1966-75)	3.14	3.56	3.45	3.30	3.56	3.66	3.87	3.66	5.10	3.51	3.56	3.20	3.61
Petaling Jaya (1971-75)	3.20	3.30	3.35	3.40	3.51	3.14	3.25	3.25	3.25	3.35	3.30	3.25	3.30
University of Malaya (1966-75)	2.78	2.78	2.78	2.32	2.68	2.68	2.53	2.58	2.58	2.78	2.78	2.68	2.68

* corrected for effective heights

(source: Malaysian Meteorological Service)

than 1.5ms^{-1} (3.0 knots), the mean annual difference between speeds outside and in the city area is about 9.0 percent. This is mainly owing to a substantial increase in the percentage frequency of winds more than 1.5ms^{-1} (3.0 knots) in the 'city' station so reducing the overall mean velocity and at the same time enhancing those in Subang.

5.4 Solar Radiation and Sunshine

The net all wave radiation, R_n, received by the earth's surface can be expressed in the form

$$R_n = (Q + q)(1 - \alpha) + LW\downarrow - LW\uparrow \quad \text{............} \quad (5.1)$$

where $Q + q$ = the global flux

Q = direct beam shortwave radiation

q = diffuse beam shortwave radiation

α = surface albedo

$LW\downarrow$ = longwave radiation received by the surface from the atmosphere

$LW\uparrow$ = longwave radiation emitted by the surface

It has generally been found that pollutants will decrease the global radiation and increase the incoming longwave (e.g. Bach, 1969). The hypothesis has been that an aerosol layer over the city absorbs some incoming shortwave (SW) and outgoing longwave (LW) during the day, and outgoing LW at night, then reradiates this heat energy with a large proportion of it arriving at the surface as $LW\downarrow$ (e.g. Bach & Patterson, 1969; Oke & Fuggle, 1972; Rouse & McCutcheon, 1973). This is the well-known 'green house' effect which has often been quoted as a cause for the development of the urban heat island (e.g. Shaw & Munn, 1971). Recently, however, some doubt has been cast on this hypothesis; the main criticism being, any surplus energy obtained in this way in the city is unlikely to be sufficient to develop a heat island (Fuggle, 1971). Fuggle's subsequent work in Johannesburg (Fuggle, 1972) shows that the role of pollutants and water vapour is probably not as important as the modification of the temperature structure in contributing to an increase in counter-radiation over urban areas.

The urban effects of solar radiation (Q + q) have generally been well documented; studies indicating urban/rural differences include those by Hand (1949), Stagg (1950), De Boer (1966), Probald (1972), Rouse & McCutcheon (1973), Tapper (1976) and are summarized in Table 49. Mateer (1961) found that in polluted urban atmosphere, Sundays generally experienced higher radiation level than weekdays by nearly 3.0 percent. Munn (1961) and Munn & Ross (1961) noted a year-round reduction in smoke on both Saturday and Sunday which accordingly affected incoming solar radiation. Chandler (1965), however, found no conclusive evidence to show that Sunday experienced higher solar radiation receipt.

Some studies have included the variation of solar attenuation with height over urban areas. McCormick & Baulch (1962) and McCormick & Kurfis (1966) were among the first to show in detail the aerosol variation up to a height of 600m (1980 feet) over Cincinnati. Subsequently, Bach (1971b) using data gathered from different roof-top levels and instrumented helicopters showed that on a 'polluted' day the lowest 1000m (3300 feet) of air attenuated about 65.0 percent of the solar beam, whereas on a 'clear' day the contribution to the total solar attenuation was still 30.0 percent. He further showed that shallow air layer increments of 45m (149 feet) near the ground contributed up to 21.0 percent to the total solar

TABLE 49

A Summary of Studies on Urban/Rural Solar Radiation Differences

Author(s)	Location	Average depletion (%)	Remarks
Hand (1949)	Boston	18.0	-
Stagg (1950)	London	8.5 12.8	sun elevation 30° sun elevation 14.3°
Renzetti (1955)	Los Angeles	10.0	-
Emslie (1964)	Toronto	5.0-10.0	-
Monteith (1966)	London	20.0	corresponding figure for London suburbs was 8.0 percent.
De Boer (1966)	Rotterdam	13.0-17.0	when compared with the urban fringe, the city received 3.0-6.0 percent less radiation.
East (1968)	Montreal	9.0	corresponding summer value was 4.0 percent with winter value of 15.0 percent.
Bach & Patterson (1969)	Cincinnati	6.0	clear skies
Yamashita (1970)	Tokyo	10.0	clear skies
Rouse & McCutcheon (1972)	Hamilton	12.0	clear skies
Probald (1972)	Budapest	7.0- 8.0	Radiation deficit for urban stations in winter averaged 15.0 percent
Yamashita (1973)	Toronto	5.0-15.0	clear skies
Sekihara (1973)	Tokyo	10.0-15.0	-
Rouse & McCutcheon (1973)	Hamilton	12.0	-
Sanderson (1974)	Windsor, Ontario	10.0	clear skies. Maximum depletion up to 25.0 percent
Tapper (1976)	Christchurch, N.Z.	14.9	clear skies

attenuation.

Works relating to the effects of aerosols on sunshine have appeared relatively less frequently in the literature compared to those of radiation. Chandler's work in London reveals that averages of bright sunshine duration decrease markedly towards central London (Chandler, 1965). The reduction in average bright sunshine amounted to a loss of 16 minutes per day in the outer suburbs and 44 minutes per day in the centre. An analysis of mean sunshine hours by days of the week appears to show notable differences, more especially between Sundays and Mondays and the remainder of the week. In Aberdeen, McBoyle (1969) found no conclusive evidence that sunshine duration decreased significantly towards the central city.

The following sections attempt to examine the extent to which the findings by previous workers discussed so far are applicable to the Kuala Lumpur - Petaling Jaya area. As available data are limited only to solar radiation and sunshine duration, the analyses that follow will necessarily be confined only to these two aspects. Solar radiation was measured using the Casella bimetallic actinograph while duration of bright sunshine was obtained using the Campbell-Stokes sunshine recorder.

5.4.1 Solar Radiation in Kuala Lumpur - Petaling Jaya

In view of what has been said (Table 49), one would expect the radiation amount received at Weld Reservoir to be less than that of Subang Airport. Table 50, however, does not substantiate this expectation. With the exception of July, the average receipt of total radiation during the recording period was higher at Weld Reservoir than at Subang in all months. This is even more evident when data for 1975 alone (in order to keep all stations on the same

TABLE 50

The Radiation at Weld Reservoir (1975) as a Percentage of that at Subang (1973-75)

J	F	M	A	M	J	J	A	S	O	N	D
119.61	103.92	105.18	109.91	108.06	109.36	98.01	106.93	110.01	111.54	107.85	110.18

(source: Malaysian Meteorological Service and Field Measurements)

time scale) are considered. In both cases the mean annual values at Weld Reservoir were 8.29 percent (all available data) and 15.97 percent (1975 data only) greater than those of Subang Airport. The t-tests performed on both groups of data showed that these differences were significant at the 0.01 level with t-values of 3.1867 and 5.3685 respectively. In order to ensure that the anomaly was not essentially due to instrumental error a re-calibration was carried out using a third actinograph as standard. No substantial differences in the readings of the instruments were however detected.

No immediate explanation for the anomaly could be offered at this stage. Nevertheless, it was thought that the greater amount of total radiation at Weld Reservoir might possibly be related to the relatively higher ground on which the station was located which was probably above some of the worst pollution which collected near street level. In contrast, the local air at Subang may probably be deteriorating as evidenced from Figure 55 which shows that the annual sunshine duration after 1972 has been consistently below the mean for the 1966-75 decade. The increase in the number of domestic and international flights at Subang Airport in the last few years could be a contributory factor. However, it is difficult, because of differences in instrument siting and the comparative brevity of the records, to be absolutely sure that the Subang radiation readings show the effect of air quality deterioration although sunshine records seem to support this view.

Figure 56 shows the hourly values of solar radiation at Subang and Weld Reservoir. In the morning up to about 1045-1145 hours (L.S.T.), the radiation receipt at Weld Reservoir is comparatively lower than that of Subang. The pattern, however, is reversed in the afternoon when Weld Reservoir records greater

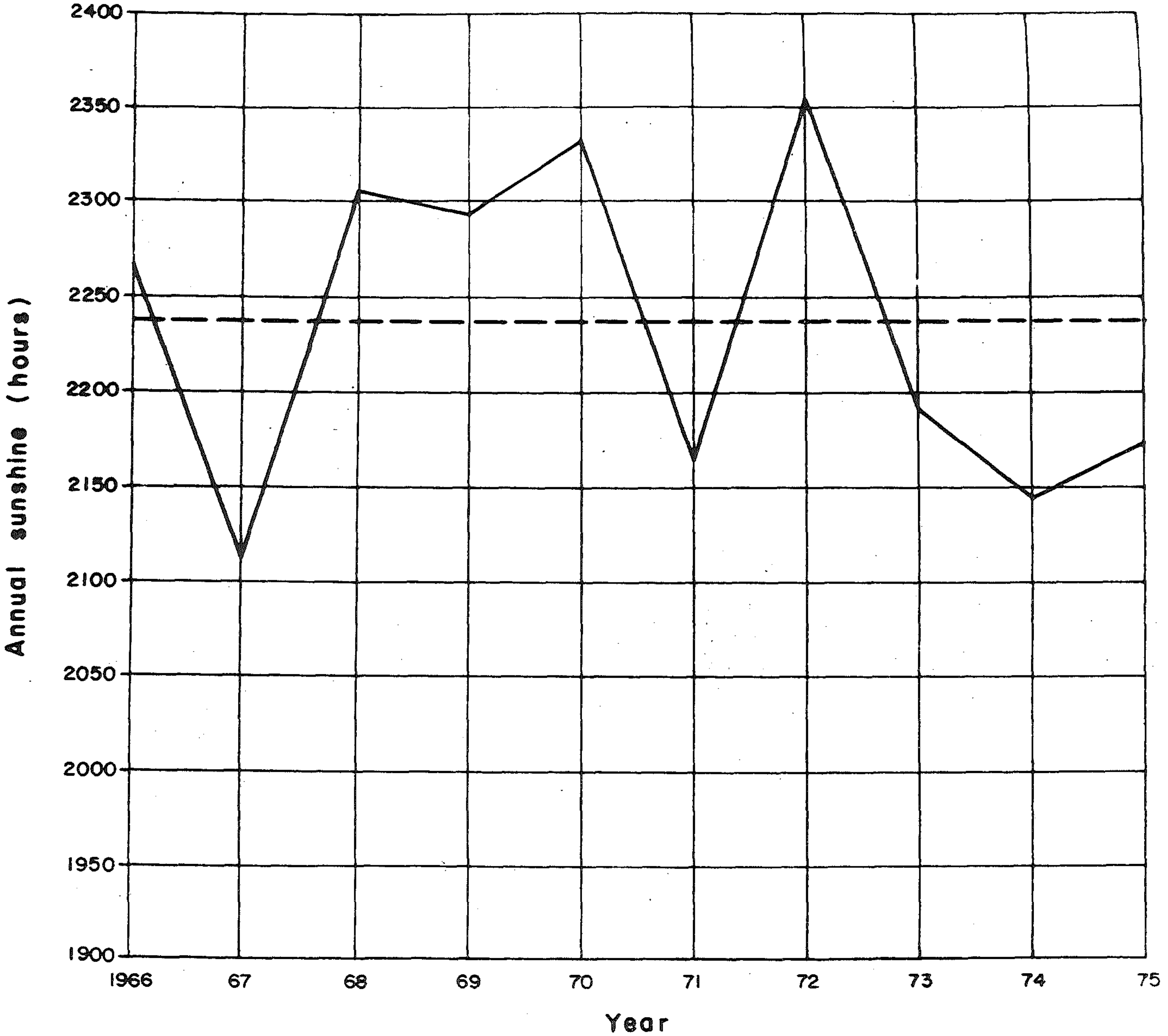


Figure 55: Annual sunshine duration for Subang, 1966-75. Broken line indicates mean duration for the 1966-75 period

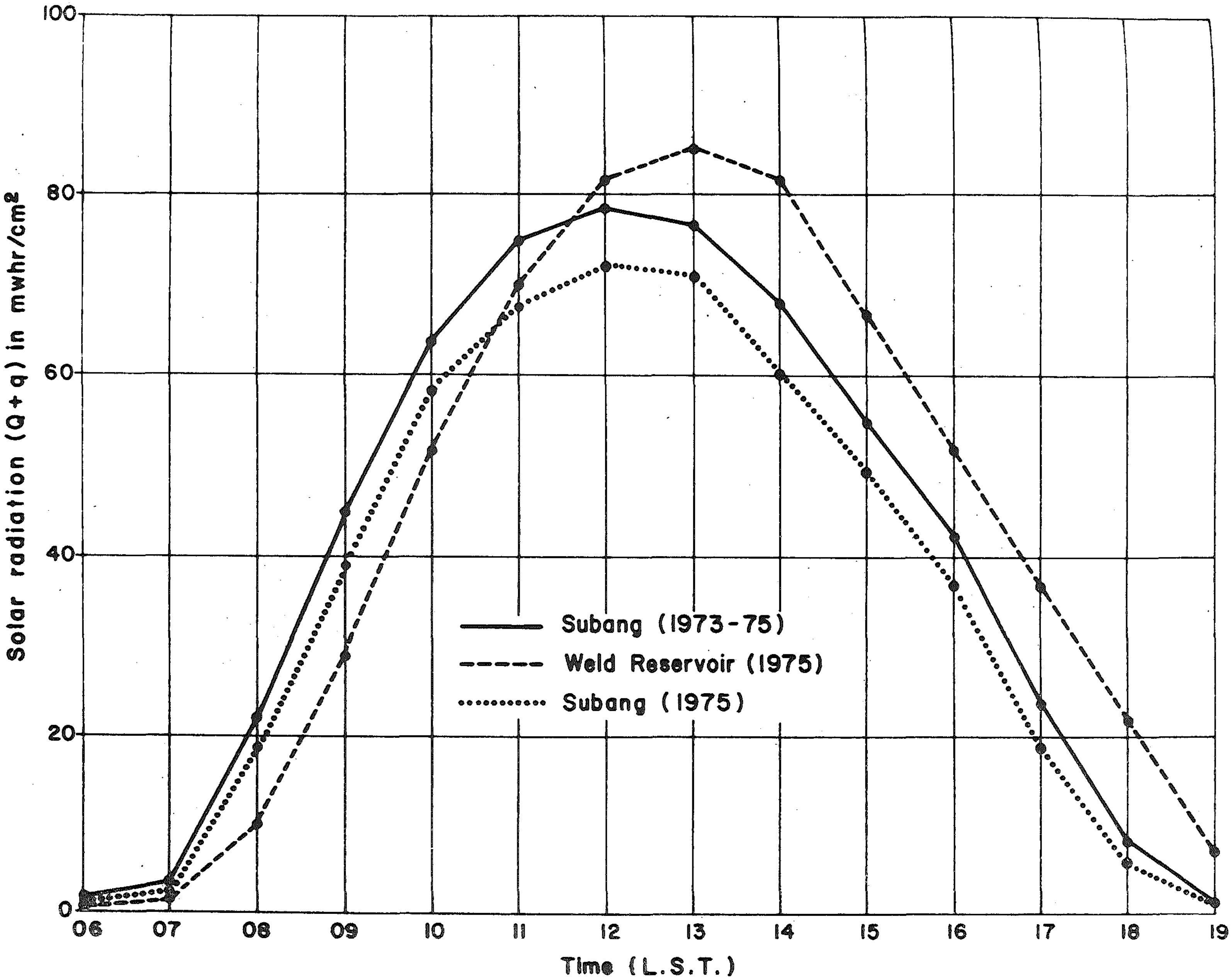


Figure 56: Hourly values of solar radiation (Q + q) in mwhr/cm^2 at Subang and Weld Reservoir, 1975

radiation receipt. This apparent lag in the hourly values of solar radiation at Subang and Weld Reservoir may be attributed, at least in part, to the general daily cycle of pollution. During the morning, as a result of traffic build-up, air pollution concentration will increase quite substantially in the city area. However, the dispersion of pollution during this period is relatively restricted particularly with low wind speed (see Chapter 2). In the afternoon, as convection becomes more vigorous, the pollutants which have been blanketing the city during the morning will then be dispersed causing the city air to clear somewhat. Obviously actual measurements of hourly pollution are needed in order to support or refute the above surmise.

The annual and monthly amounts of total radiation for each day of the week as recorded at Weld Reservoir are given in Table 51. Contrary to several findings elsewhere (e.g. Mateer, 1961; Munn, 1961; Munn & Ross, 1961), no difference was observed either between Sunday and remainder of the week or between Saturday-Sunday and remainder of the week. The ratio in both cases were 1.00 : 1.06, and 1.00 : 1.04 respectively with t-values of 0.9022 and 0.4239 neither of which was significant at the 0.05 level. This compares favourably with those obtained by Chandler (1965) in London. He contends that changes in pollution concentrations and hence their effects on incoming solar radiation are submerged by larger and more irregular fluctuations owing to molecular scattering, reflection from and absorption by clouds and selective absorption by water vapour. The relatively greater amount of humidities and cloudiness in Kuala Lumpur - Petaling Jaya as compared with those of London (Chandler, 1965) makes these two factors even more pertinent in the case of the present study. It was therefore decided that an

TABLE 51

Average Amount of Solar Radiation on a Horizontal Surface, by Days of the Week and Months of the Year at Weld Reservoir (1975). Values are in $mwhr/cm^2$

month	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jan	630.65	626.88	706.62	609.26	649.28	633.13	663.40
Feb	614.38	565.05	520.80	697.05	678.35	669.68	409.85
Mar	594.35	655.23	662.84	651.70	627.15	662.36	688.52
Apr	686.67	627.54	624.24	689.53	605.73	565.73	603.05
May	628.20	535.25	595.45	574.90	650.32	626.72	639.07
Jun	559.26	649.58	519.76	610.09	576.24	595.06	563.93
Jul	559.19	574.50	567.78	498.57	590.99	474.55	489.80
Aug	568.85	560.86	662.08	680.88	622.88	672.85	570.40
Sep	687.51	536.38	574.93	657.55	607.50	573.70	604.78
Oct	623.25	648.90	634.86	682.56	548.60	652.70	607.40
Nov	523.63	552.93	508.50	498.28	560.38	538.58	577.78
Dec	514.58	562.80	603.14	678.53	619.80	568.80	436.43
Year	599.21	591.33	598.42	627.41	611.44	602.80	571.20

(source: Field Measurements)

examination of the relative effect of water vapour and air pollution upon solar radiation was necessary. An estimate of transmissivity, T_r, was subsequently attempted using the partially empirical equation of Brooks (1959) in the form

$$T_r = \exp\left[(-0.089)(pm/1013)^{0.75} - 0.174(wm/20)^{0.6} - 0.083(dm)^{0.9}\right] \quad \text{............ (5.2)}$$

where T_r = transmittance of whole spectrum direct beam solar radiation

p = air pressure (mb)

w = water vapour (mm)

d = dust

m = optical air mass

The simulation was applied to atmospheric data from the city station at Weld Reservoir taking the high, medium and low values for water vapour and respirable dust particulates. Moisture characteristics were converted to precipitable water vapour using the Reitan equation in the form

$$\text{log natural } w(\text{cm}) = -0.981 + 0.0341D \quad \text{......... (5.3)}$$

where D = surface dewpoint ($^{\circ}$F)

(Reitan, 1963)

Respirable dust particulates were converted to particles/c.c. at the ratio of 1.0 particle for every 100$\mu g/m^3$ of dust (Tapper, 1976).

The results indicate that in extreme cases (i.e. when high water vapour - low dust combination was compared with that of low water vapour - high dust) the effect of water vapour can be up to 12.0 percent greater than that of dust particulates. When medium water vapour - low dust combination was compared with that of low water vapour - medium dust, a difference of 4.26 percent was observed in favour of water vapour. It thus appears that the explanation given by Chandler (1965) for the lack of any significant difference between weekend and weekdays in London may well apply in the case of Kuala Lumpur - Petaling Jaya. However, further studies are necessary before any definite conclusion can be drawn.

5.4.2 Sunshine in Kuala Lumpur - Petaling Jaya

Reduction in the duration of bright sunshine by the urban atmosphere of Kuala Lumpur - Petaling Jaya is more immediately obvious and much more readily analyzed than that of radiation for there are more available stations in and around Kuala Lumpur - Petaling Jaya with relatively longer sunshine records.

Table 52 shows that with the exception of University of Malaya, annual averages of bright sunshine decrease quite markedly towards the centre of Kuala Lumpur despite the high altitude of Weld Reservoir. Compared with that of Subang, the reduction in average bright sunshine in the Kuala Lumpur city area amounted to 9.68 percent. A similar pattern prevails when the four stations are compared on the basis of the 1975 data alone. In this case, the reduction in average bright sunshine in the Kuala Lumpur city when compared to that of Subang amounted to 9.32 percent. None of the figures, however, was significant at the 0.05 level on the two-tailed t-test, the latter values being 1.8398 and 1.5728 respectively.

That the mean radiation value in the city area was greater and the sunshine value smaller when compared to those of Subang appeared to be anomalous and did not compare particularly well with results obtained elsewhere. As in the case of solar radiation, no

TABLE 52

Averages of Bright Sunshine (hours/day) at Subang, Petaling Jaya, University of Malaya and Weld Reservoir by month

Station	J	F	M	A	M	J	J	A	S	O	N	D	Y
Subang (1966-75)	6.16	6.71	7.12	6.73	6.74	6.29	6.40	6.13	5.57	5.59	4.97	5.07	6.12
Petaling Jaya (1971-75)	6.04	6.16	6.31	5.99	6.59	4.36	6.46	5.57	5.13	5.39	4.58	4.52	5.59
University of Malaya (1966-75)	6.02	6.32	6.58	6.59	6.73	6.25	6.37	5.92	5.10	5.30	4.94	4.93	5.92
Weld Reservoir (1975)	6.79	5.75	5.28	6.11	6.29	4.56	5.28	6.54	5.40	5.75	4.50	4.80	5.58

(source: Malaysian Meteorological Service, University of Malaya, and Field Measurements) immediate explanation could be offered. Nevertheless, one possible reason for the anomaly would be that while the recording site in the city was elevated and above some of the worst city street pollution, that at the airport was gradually being affected by pollution both from aircraft exhausts and the urbanized area of Kuala Lumpur - Petaling Jaya (see section 5.7). That over the past three years, the mean annual value of sunshine at Subang Airport was consistently below the decade (1966-75) average had been noted earlier (Figure 55). Although mean sunshine value in the city area was observed to be in excess of that of Subang, the percentage difference was small and not significant at the 0.05 level.

Results of analysis of mean annual and monthly sunshine duration by days of the week for Weld Reservoir and Petaling Jaya are shown in Table 53. As in the case of solar radiation and contrary to several findings elsewhere (e.g. Chandler, 1965), no difference was observed either between Sunday and remainder of the week or between Saturday-Sunday and remainder of the week. This applies both to Weld Reservoir as well as Petaling Jaya. For Weld Reservoir, the ratios for Sunday versus remainder of the week and Saturday-Sunday versus remainder of the week were 1.00 : 1.05 and 1.00 : 0.99 respectively with t-values of 0.4997 and 0.1390 neither of which was significant at the 0.05 level. The corresponding figures for Petaling Jaya were 1.00 : 0.98 and 1.00 : 0.97 with t-values of 0.2390 and 0.2647 which were insignificant at the 0.05 level. If these are physically controlled and accidental occurrences, they are probably similarly explained as those of solar radiation.

TABLE 53

Average Amount of Bright Sunshine Hours (hours/day) by Days of the Week and Months of the Year at Weld Reservoir and Petaling Jaya

month	station	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jan	A	7.88	6.48	6.99	6.39	6.15	6.01	6.84
	B	6.11	4.62	6.05	7.43	6.53	6.04	6.52
Feb	A	6.24	5.26	7.75	6.06	5.76	6.43	3.56
	B	6.01	6.24	6.18	5.42	5.81	7.41	6.47
Mar	A	3.83	4.00	4.68	5.51	4.68	7.68	5.99
	B	6.30	6.39	6.15	6.43	6.05	6.41	7.06
Apr	A	7.19	5.63	5.64	7.48	4.96	5.85	6.26
	B	5.71	6.15	4.57	6.22	5.82	6.75	5.91
May	A	6.98	4.89	6.39	5.50	7.35	5.62	6.40
	B	6.49	6.99	6.89	7.65	4.95	7.37	5.65
Jun	A	4.05	3.96	5.68	3.85	4.14	3.38	6.52
	B	5.59	4.44	4.80	4.72	4.23	3.95	3.28
Jul	A	3.73	6.13	6.30	6.07	3.60	6.38	4.03
	B	4.40	7.66	6.96	5.75	6.03	6.24	6.92
Aug	A	7.51	6.58	5.80	5.80	6.55	6.41	6.31
	B	4.56	6.24	6.43	6.26	5.14	5.14	6.02
Sep	A	5.83	5.30	4.49	5.65	4.48	6.95	3.71
	B	4.80	6.27	4.11	4.00	4.99	6.36	5.44
Oct	A	5.96	5.49	4.43	6.70	5.37	6.07	5.89
	B	5.63	5.75	5.72	5.27	4.17	4.51	6.17
Nov	A	3.98	3.65	4.56	3.88	5.71	3.79	5.25
	B	4.89	4.38	4.47	5.19	3.91	4.50	4.40
Dec	A	2.80	5.26	4.89	5.52	6.66	5.78	2.84
	B	3.24	4.06	4.55	5.33	3.79	3.42	3.56

A: Weld Reservoir (1975)
B: Petaling Jaya (1971-75)

(source: Malaysian Meteorological Service and Field Measurements)

5.5 Temperature

Investigations into the heat island have established that not only the temperature discontinuity between the latter and the surrounding area is distinctive both in time and space but its horizontal structures are also complex. During the day, the spatial variations of temperature away from the central city may not be very pronounced (e.g. Preston-Whyte, 1970; Chandler, 1963 & 1964; Munn *et al*, 1969; Ludwig, 1967; Ludwig & Kealoha, 1968). In some instances daytime city temperatures may even be lower than those of the suburbs (Landsberg, 1956). By night, the differences between regions of maximum heating and cooling can be quite large (Reichel, 1933; Bornstein, 1968; Oke & East, 1971). The complicated horizontal structures of the urban heat island have been well documented by Sundborg (1950), Duckworth & Sandberg (1954), Mitchell (1961), Chandler (1965), Woollum & Canfield (1968), Oke (1969), and Munn *et al* (1969).

The study of the surface form and intensity of urban heat island has led to the suggestion that the latter parameter is dependent on city size (Mitchell, 1953, 1961 & 1962; Dronia, 1967; Landsberg, 1960; Lawrence, 1968). The relation between city size and urban-rural temperature difference is not linear, however; sizeable nocturnal temperature contrasts have been measured even in relatively small cities (e.g. Hutcheon *et al*, 1967; Sekiguti, 1964; Landsberg, 1970; Kopec, 1970; Fonda *et al*, 1971; Sekiguti *et al*, 1972).

Investigations of vertical temperature profile within and near urban areas have shown that thermal influence of a large city commonly extends up to 200-300m and even to 500m and more. The decreases in frequency and intensity of inversions, due to increased thermal and mechanical convection, are now well established. Summers (1964) suggested that this increased mixing would result in an adiabatic layer over the city, and that this urban boundary layer could be visualized to develop in a manner similar to flow of air over a heated plate. Clarke (1969) was the first to verify observationally the Summers urban boundary layer concept, using helicopter traverses across Columbus, Ohio. Further evidence is given by Oke & East (1971) for Montreal, P.Q. and by Tyson _et al_ (1972) for Johannesburg. Evidence of contrasted lapse rates over urban and adjacent areas has been obtained by Duckworth & Sandberg (1954) for San Francisco, by Shitara (1959), Yamamoto & Shimonuki (1964), and Sekiguti (1970) for Japanese towns, McCormick & Baulch (1962), and McCormick & Kurfis (1966) for Cincinnati, Munn & Stewart (1967) for sites in southern Ontario, Davidson (1967) and Bornstein (1968) for New York, Georgii (1970) for Frankfurt, and Yap _et al_ (1969) and Oke & East (1971) for Montreal.

There have also been attempts to seek some degree of generalization concerning the nature of the urban heat island based on semi-empirical or wholly empirical grounds. These generally fall into four categories: _statistical_ (e.g. Sundborg, 1950; Chandler, 1965; Oke & Hannell, 1970; Oke, 1972), _energy balance_ (e.g. Myrup, 1969 & 1970; Outcalt, 1970, 1971 & 1972; Goddard, 1971; Myrup & Morgan, 1972; Terjung, 1969 & 1971; Oke _et al_, 1972), _mixing depth_ (e.g. Summers, 1964; Clarke, 1969; Oke & East, 1971; Leahey, 1969), and _dynamic_ (e.g. Malkus & Stern, 1953; Wagner & Yu, 1972; Molenkemp, 1968; Crowley, 1968). The several attempts to model the heat islands have been reviewed by Tyson _et al_ (1973) and Oke (1974).

In common with other cities, Kuala Lumpur - Petaling Jaya displays many of the temperature characteristics found in a 'typical' city. Table 54 indicates that the mean temperature increases steadily as one approaches the central city. By night the contrasts between the central station and its surroundings are more marked. The lowest minimum value recorded at the University of Malaya is due largely to the altitude effects, exposure, and site peculiarities of the station. This is further evident by the generally high maximum and low minimum temperatures recorded here. In the case of the minimum temperatures at Weld Reservoir, however, the influence of the city's warmth appears to be more dominant than either altitude or exposure effects. A comparison using only the 1975 figures in order to keep data period for all stations on the same time basis shows similar results although the magnitude of the difference is smaller.

TABLE 54

Average annual temperatures at stations in Kuala Lumpur-Petaling Jaya, 1966-75. Figures are given in °C

station	Height above mean sea level	max	min	mean
Subang (1966-75)	30.6m	31.6	22.7	27.2
Petaling Jaya (1971-75)	45.5m	32.2	23.2	27.7
University of Malaya (1966-75)	103.0m	34.6	21.2	27.9
Weld Reservoir (1975)	65.8m	31.8	24.4	28.1

(source: Malaysian Meteorological Service and Field Measurements)

Temperature differences at Petaling Jaya, University of Malaya, and Weld Reservoir with those at Subang graded and by month, are illustrated in Figures 57, 58 and 59 respectively. In each case, differences refer to temperatures from Petaling Jaya, University of Malaya and Weld Reservoir minus that of Subang. The number of occurrence of temperature difference within each category is expressed as percentage for each month. These indicate that with maximum temperatures for Petaling Jaya and the University of Malaya at least 58 percent of the days have positive anomalies. This is not the case, however, with Weld Reservoir. Here the period January-July has at least 78 percent of the days with positive anomalies while during August-December inclusive days with negative anomalies are relatively more dominant. There is no immediate explanation for this pattern but it could perhaps be due to the several defective records during these months. The correlation coefficient of the regression equation used to estimate the missing values was only 0.58 (Appendix E). Results shown in Figure 59 should therefore be interpreted with caution.

The patterns for differences in daily minimum temperatures at the three stations differ quite markedly from one another. In all cases, the patterns once again reflect the effects of their respective locations in relation to the city centre, plus site, exposure and altitude differences. The anomalous pattern during August-December at Weld Reservoir most probably reflects the incomplete records during these months.

Figure 60 shows the average hourly temperature difference, by month, between Petaling Jaya and Subang for the years 1971-75. It is noted that positive anomalies of 0.6°C (1.0°F) or greater can occur anytime between 1900 and 0800 hours (LST); the actual

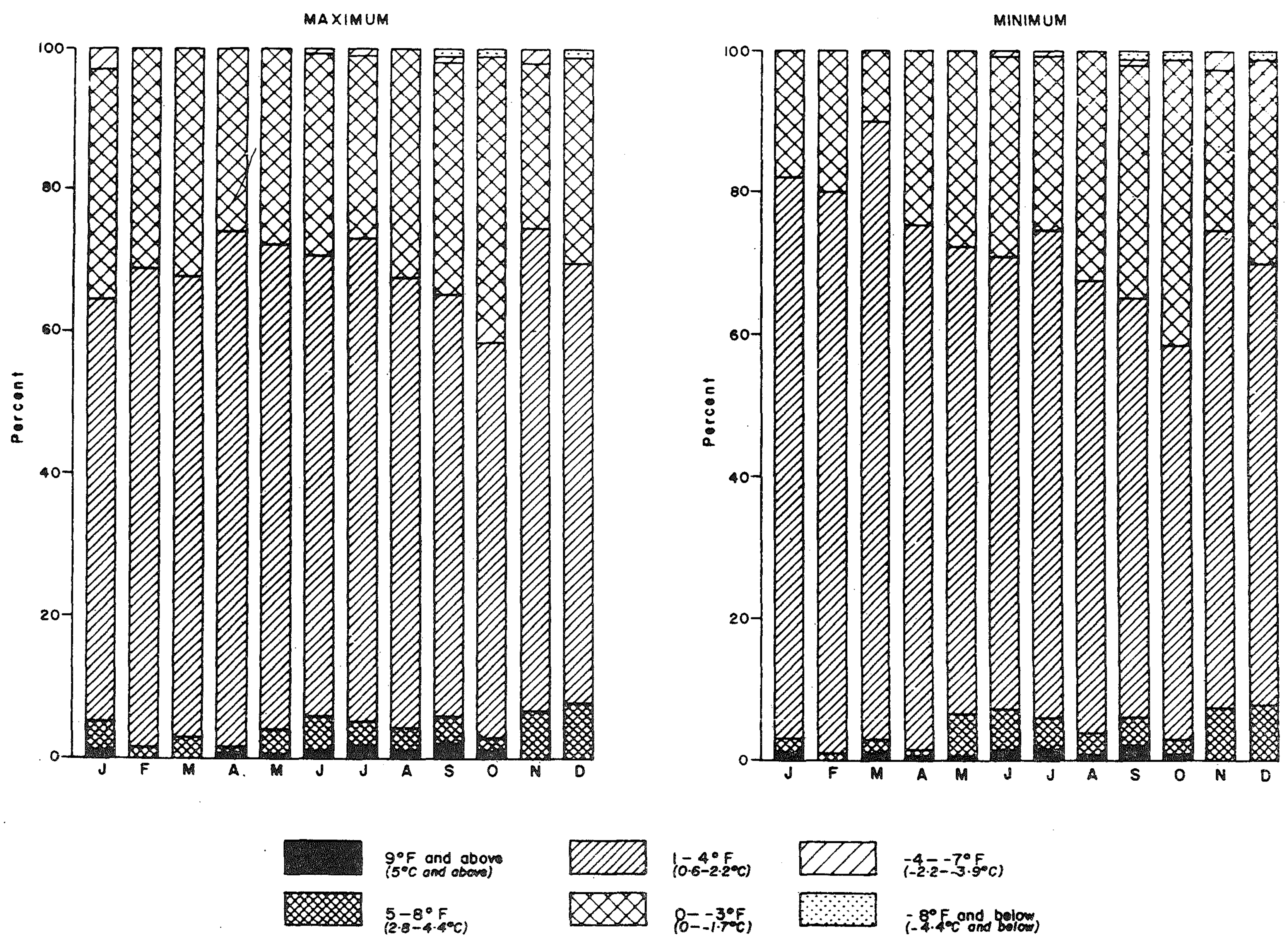


Figure 57: Differences in daily maximum and minimum temperatures, Petaling Jaya - Subang, by month, 1971-75

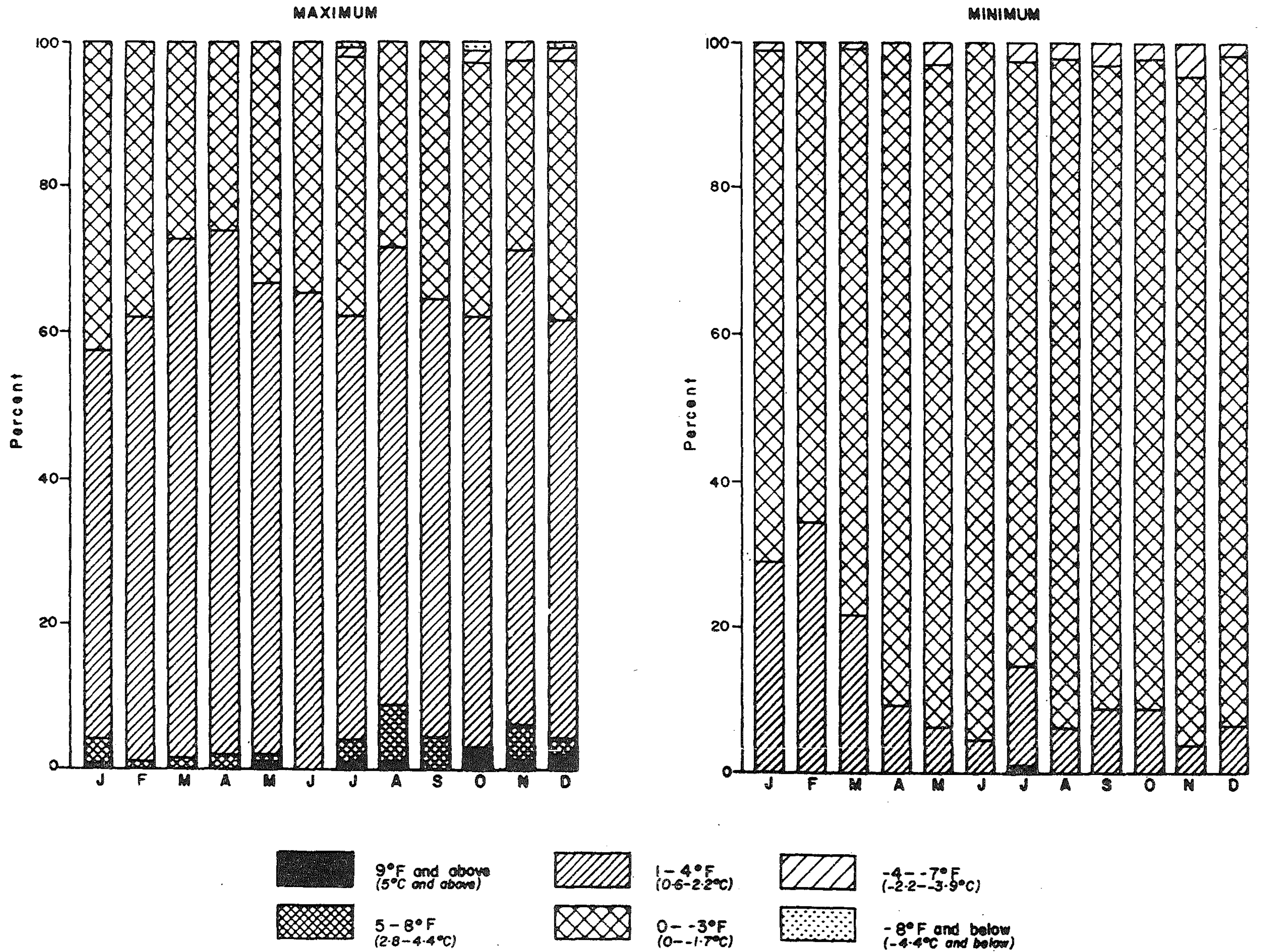
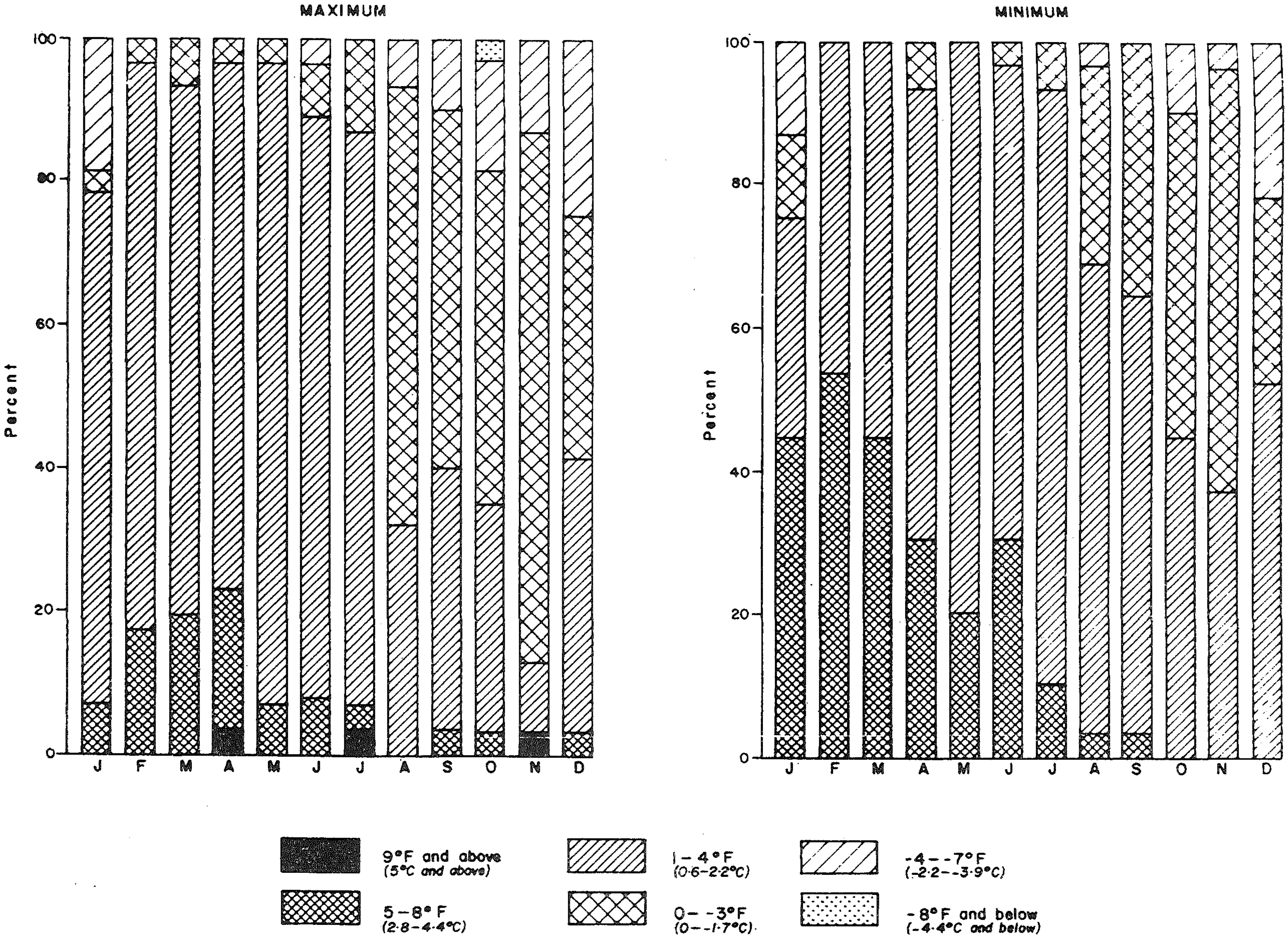


Figure 58: Differences in daily maximum and minimum temperatures, University of Malaya - Subang, by month, 1966-75

Figure 59: Differences in daily maximum and minimum temperatures, Weld Reservoir - Subang, by month, 1975



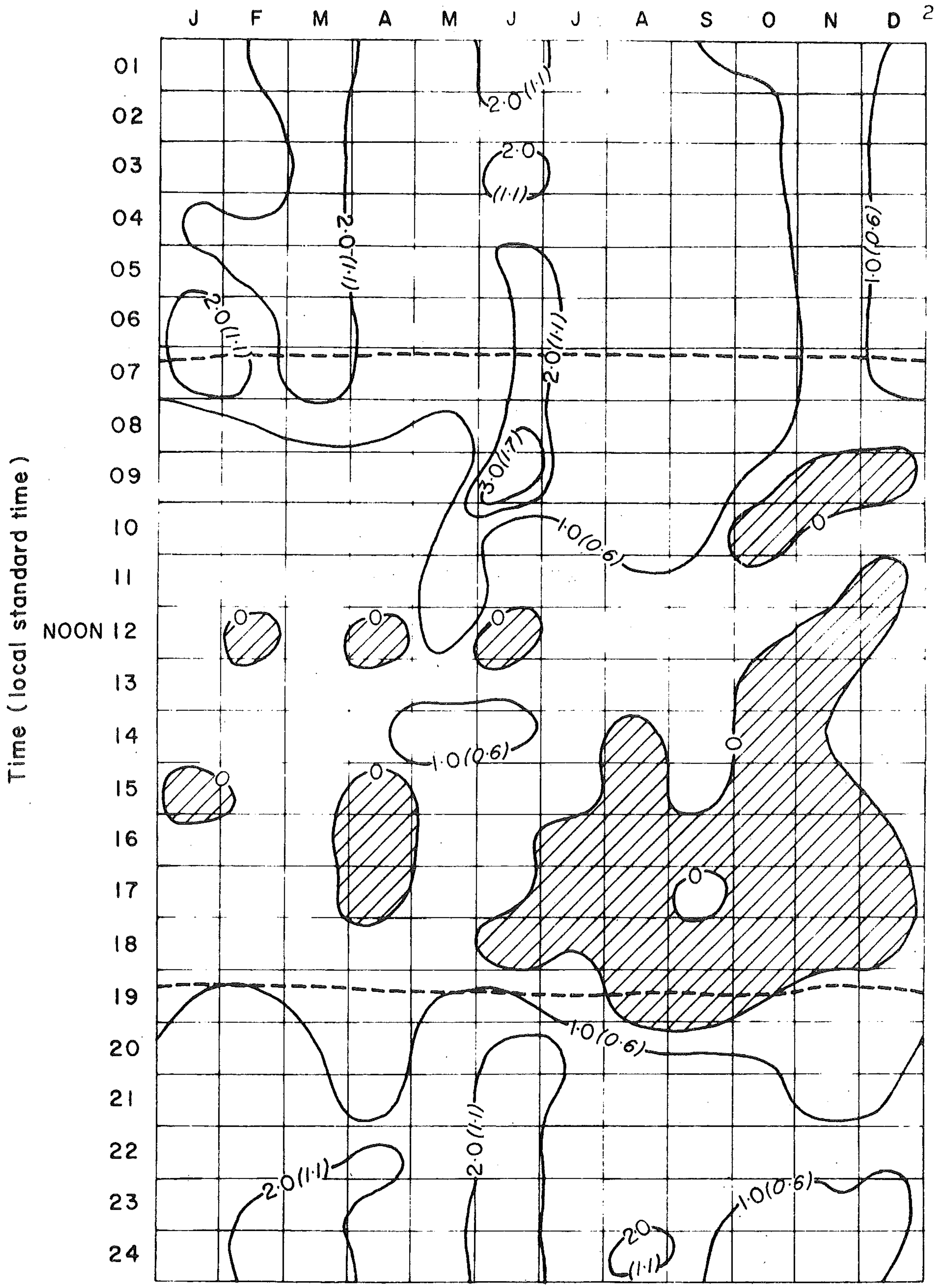


Figure 60: Average hourly temperature difference between Petaling Jaya - Subang, 1971-75. Broken lines indicate times of sunrise and sunset. Negative differences for Petaling Jaya are shaded. Values are given in °F with their equivalents in °C shown in brackets

times, however, vary from one month to the next. Negative temperature anomalies at Petaling Jaya are recorded mostly during the afternoon particularly between June and December inclusive. In general, the magnitude of the difference is small; only occasionally that it exceeds 0.6°C (1.0°F).

The heat island effect of Kuala Lumpur - Petaling Jaya was also examined using the traverse method. Temperatures were measured using whirling hygrometers along predetermined routes (Figures 61 & 62) with the help of several third year Geography students of the National University of Malaysia. The study area was divided into nine sectors, each being assigned to several observers on scooters. The number of observers in any one sector was decided on the basis that the measurement should not last more than one hour. Thus although manual instruments were employed, the shortness of time taken made possible by the participation of a number of observers eliminate any great change in weather conditions during the measuring period. All whirling hygrometers were calibrated using YSI Model 44 tele-thermometer as standard. Errors in the temperature readings can be taken to be less than $\pm$ 0.56°C ($\pm$ 1.0°F).

Figure 63 shows the results of two night-time traverses taken between 2100 and 2200 hours (local time) in Kuala Lumpur - Petaling Jaya on 3rd December, 1975 under calm and clear-sky night. Total daily sunshine and solar radiation as recorded at Subang were respectively 11.0 hours and 636.8 mwhr/cm^2. Generally, the temperature profiles reflect both the changing landuse types as well as man's activities along the traverse routes. The steep temperature increase between stations 23 and 24 in the top diagram, for example, coincided well with an increase in building density and

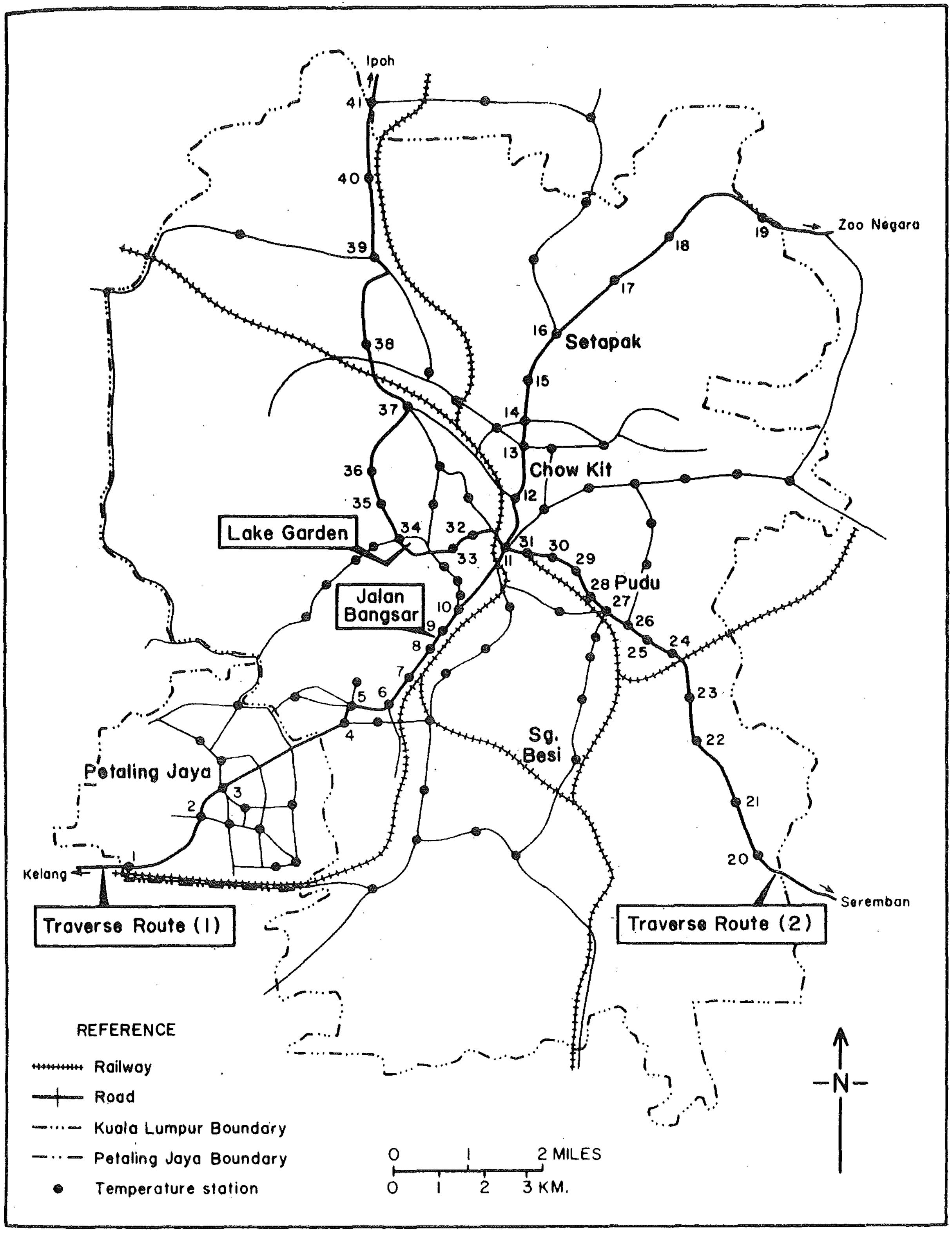


Figure 61: Kuala Lumpur - Petaling Jaya showing location of temperature and humidity stations

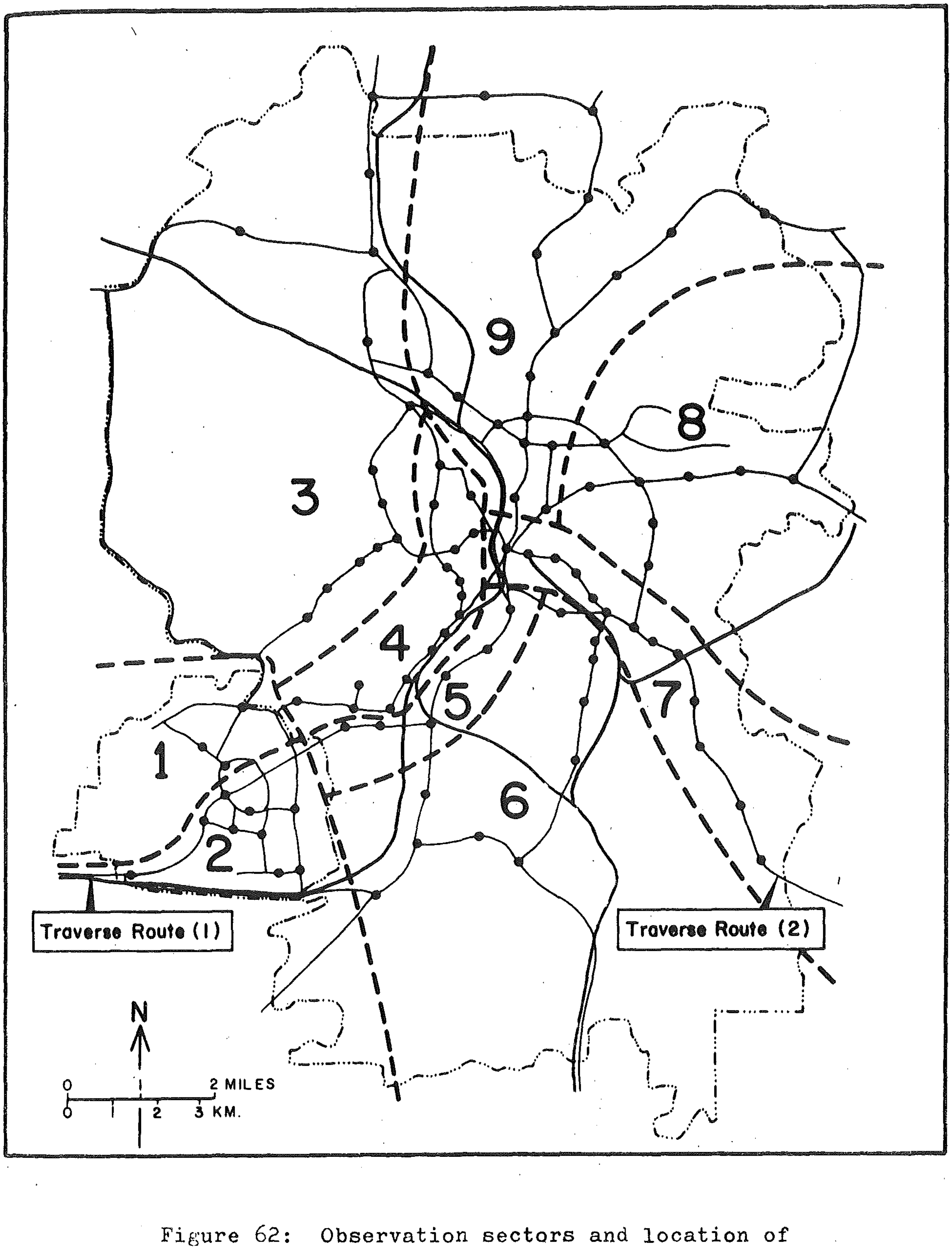


Figure 62: Observation sectors and location of temperature and humidity stations in the Kuala Lumpur - Petaling Jaya area

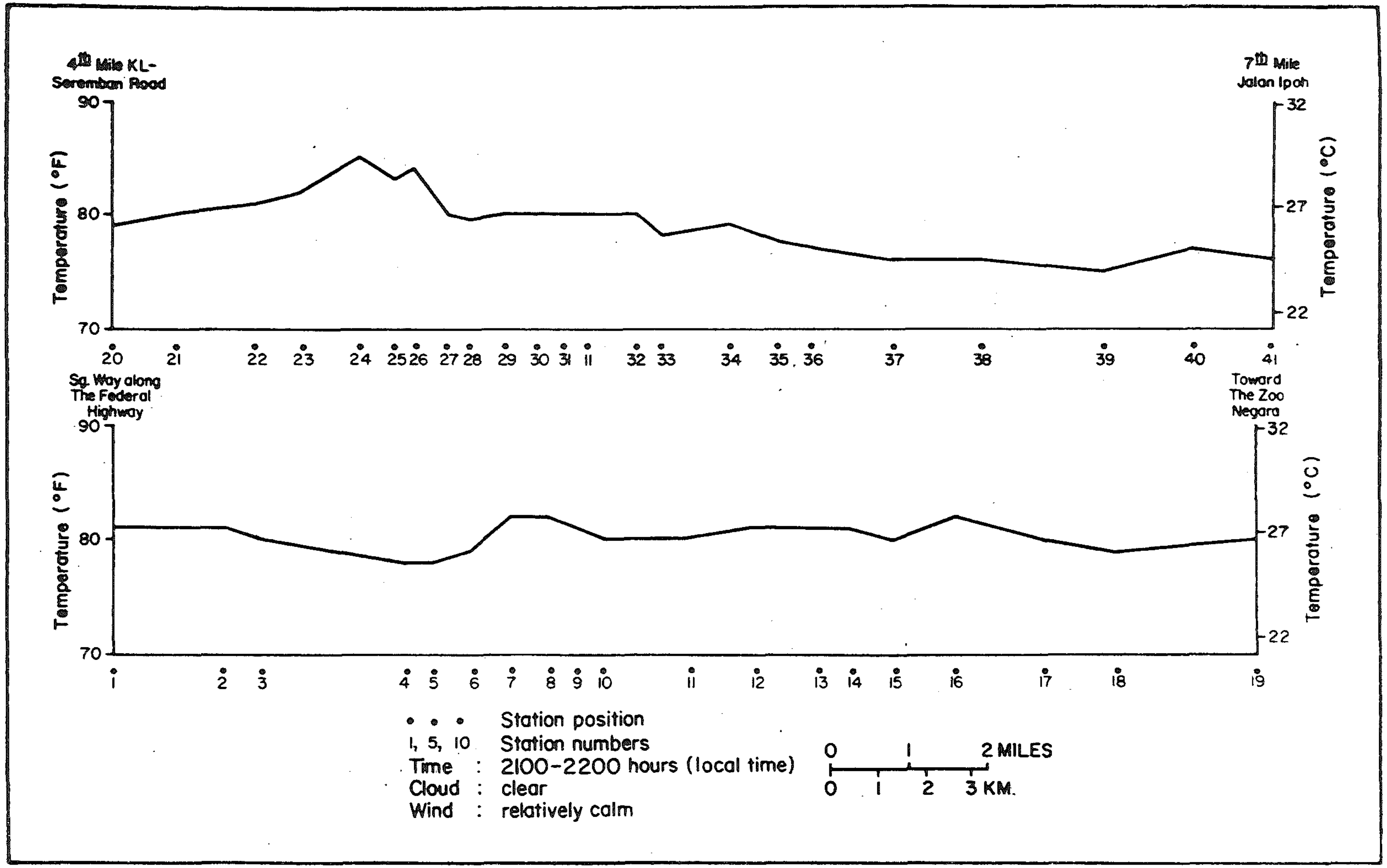


Figure 63: Temperature traverses in the Kuala Lumpur - Petaling Jaya area on 3rd December, 1975 during 2100-2200 hours (L.T.) under calm and clear-sky condition

motor vehicles as well as human activities particularly at the Jalan Pudu - Jalan Sg. Besi intersection. The decrease in temperature from station 26 until the city centre, on the other hand, reflects a corresponding decline in human activities and motor vehicles along this part of the traverse. Movement away from the central area resulted in a corresponding lowering of temperature except for a small increase at station 34 which was located at a road junction to Kuala Lumpur from Damansara Height, Petaling Jaya and beyond.

The bottom diagram of Figure 63 shows a temperature traverse from Sg. Way along the Federal Highway towards the Zoo Negara. Once again the intricate and changing distribution of warm and cool pockets of air along the traverse became apparent reflecting not only the cellular urban morphology but also thermals rising spasmodically from perhaps temporary areas of warming. One such example was noted at stations 7 and 8 which were located in the vicinity of Taman Ghazali Shafie, an eating complex along Jalan Bangsar where crowds of people came to eat out in an open air style. This coupled with open fire cooking and passing motor vehicles had caused the air to become warmer. From here the temperature decreased to about 26.6^{o}C (80^{o}F) at stations along Jalan Tuanku Abdul Rahman in the inner city. Temperature increases were noted further along at the Jalan Chow Kit shopping area and the suburban centre of Setapak. Proceeding towards the periphery from Setapak a decrease of temperature was once again evident.

The traverse in Figure 63 together with other temperature readings taken during the survey were used as a basis from which to interpolate the pattern of temperature distribution in Kuala Lumpur - Petaling Jaya for the evening of the traverse (Figure 64). It is

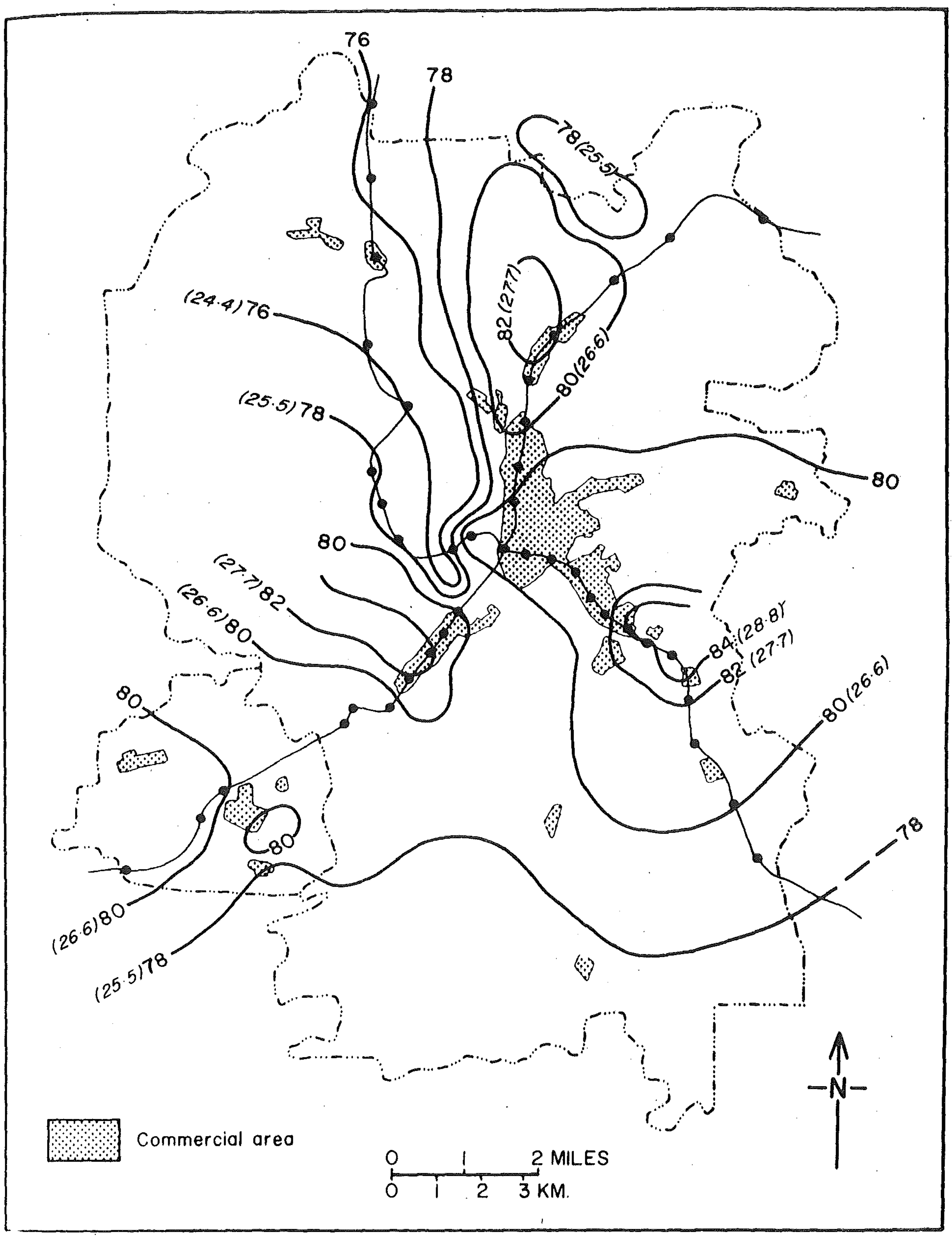


Figure 64: Distribution of temperatures taken between 2100-2200 hours (L.T.) in Kuala Lumpur - Petaling Jaya, 3rd December, 1975 under calm and clear-sky conditions. Isotherms are numbered in ^{o}F with their equivalents in ^{o}C shown in brackets

interesting to note that the maximum temperature recorded during the survey (29.4°C or 85°F) did not coincide with the commercial centre of Kuala Lumpur but slightly displaced to the southeast at Pudu. Unlike Pudu and Jalan Chow Kit, shops within the commercial centre of Kuala Lumpur are normally closed at night thus making the latter almost 'deserted'. The temperature gradient along the boundary between Kuala Lumpur commercial centre and the Lake Garden was also evident even though it was rather gentle. In many respects, the temperature patterns shown in Figure 64 confirm many of the features obtained in an earlier study by the writer (Sham, 1973c & d).

Figure 65 shows the distribution of daytime temperatures in Kuala Lumpur - Petaling Jaya taken between 1200 and 1300 hours (local time) on 10th August, 1975. The meteorological station at Subang recorded cloud cover as being 7/8 for the whole period of observation with total daily sunshine duration of 3.8 hours. Total daily solar radiation was $461.4 \mathrm{mwhr/cm}^2$ with wind from SE-S blowing at an average speed of $4.41 \mathrm{ms}^{-1}$ (9.8 m.p.h.). Two interesting features emerge when temperature patterns shown in Figures 63 and 64 are compared with those of Figure 65 and a similar map of temperature distribution presented by Sham (1973d, p.64). The first is that while the shopping complexes along Jalan Tuanku Abdul Rahman showed up as an area having one of the highest temperatures during the day-time survey, this was not true at night. The reason being: although the shopping complexes along Jalan Tuanku Abdul Rahman were crowded with people during the day and this coupled with a great density of motor vehicles passing through increased the temperature here, at night the shops were closed and human activities were virtually nil. The only places which would be operative at night were the night clubs and milkbars, which were

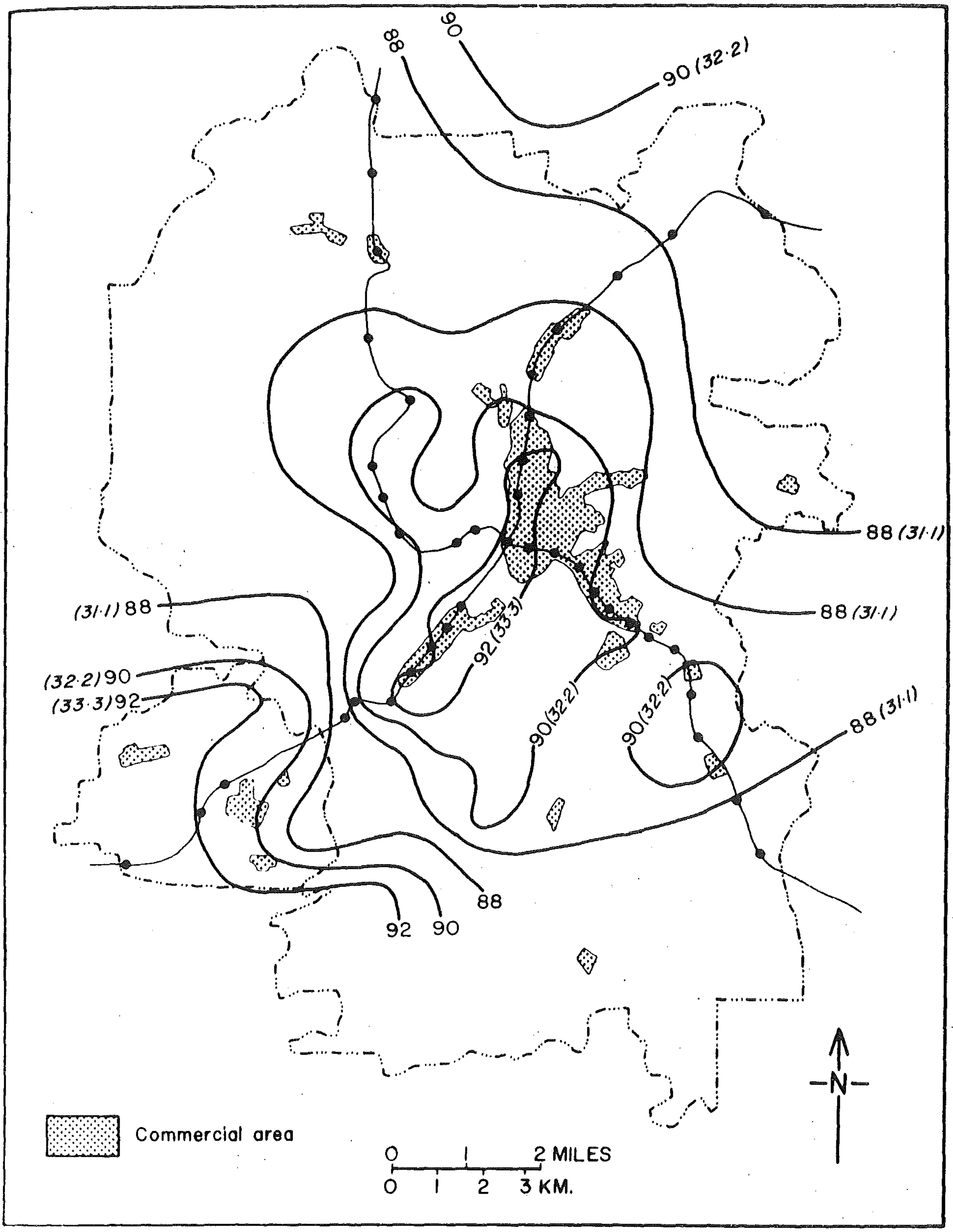


Figure 65: Distribution of daytime temperatures taken between 1200-1300 hours (L.T.) in Kuala Lumpur - Petaling Jaya, 10th August, 1975. Isotherms are numbered in ^{o}F with their equivalents in ^{o}C shown in brackets

not many any way, and these would not add substantially to the temperature increase. This is quite different in the case of Pudu, Chow Kit, Jalan Petaling, and several other shopping areas within Petaling Jaya. Here business goes on till late at night with open fire cooking as a common feature among the road-side stalls.

The second feature which is observed from comparison of map in Figure 63 and that of Sham (1973d) is that the apparent 'cliff' in the temperature field between the commercial centre of Kuala Lumpur and the vegetated surface of the Lake Garden shown by Sham in early 1972 was not too evident in Figure 63. One possible reason is that the weather conditions in the two cases (although in both cases the surveys were taken during calm and clear-sky nights following exactly the same procedures) were not identical and hence the divergence in patterns. But another possible reason, which seems to be more likely, is the increase in traffic density going through the Lake Garden particularly with the increase in residential development in Petaling Jaya, Subang/Sg. Way, and Damansara Height followed by the widening of the Damansara-Kuala Lumpur road. As temperature stations in the survey were all located along road networks, any substantial change in traffic volume would affect the temperatures.

The form and intensity of the heat island vary not only with time of day but also with weather conditions. Figure 66 shows the distribution of temperature taken between 2100 and 2200 hours on 25th November, 1975 under cloudy conditions. Figure 67 shows two temperature traverses along routes (1) and (2) taken during the same period. By comparison, both the distribution maps and the traverses show a less well-developed heat island ($2.8^{o}C$ or $5.0^{o}F$).

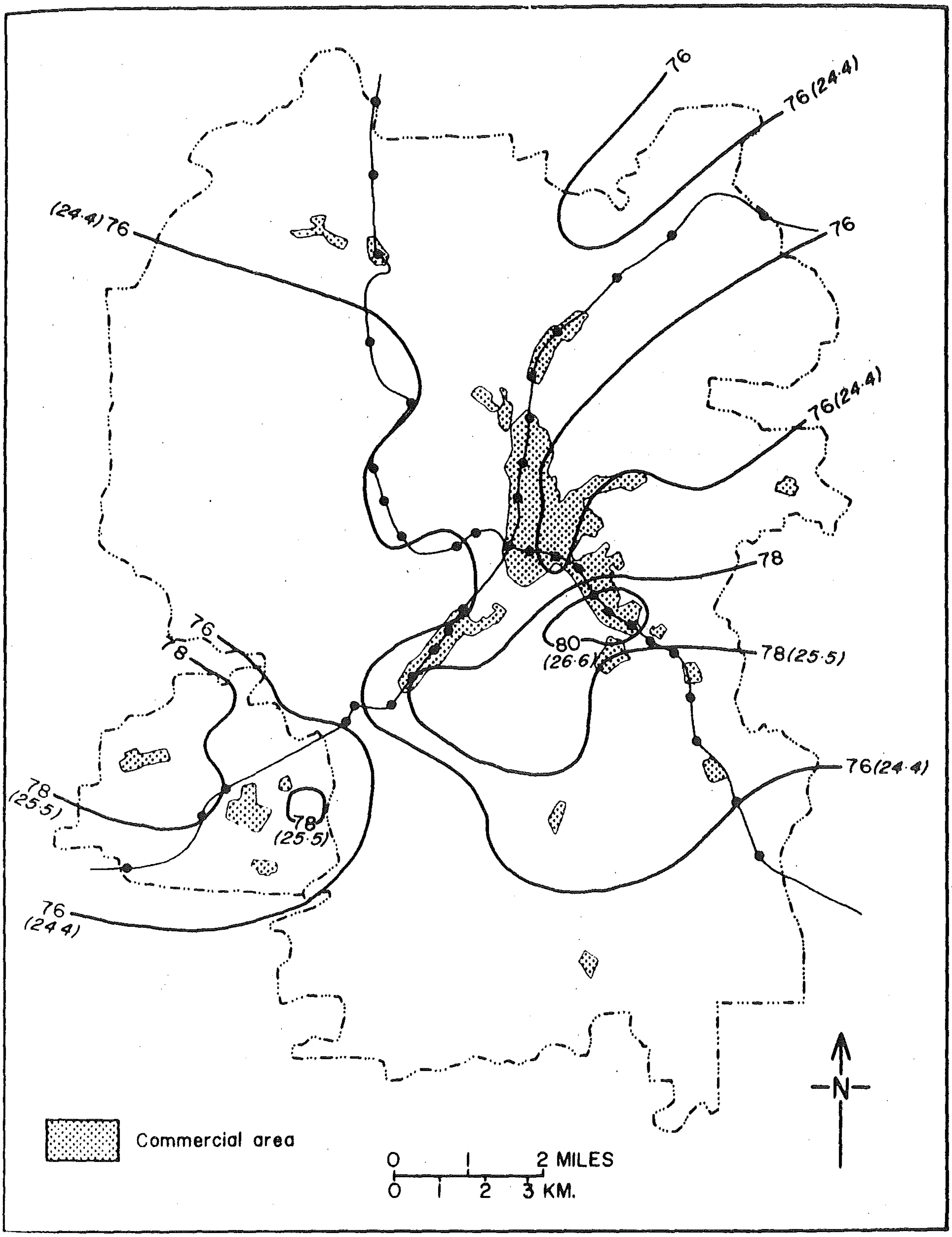


Figure 66: Distribution of temperatures taken between 2100-2200 hours (L.T.) in Kuala Lumpur - Petaling Jaya, 25th November, 1975 under cloudy conditions. Isotherms are numbered in °F with their equivalents in °C shown in brackets

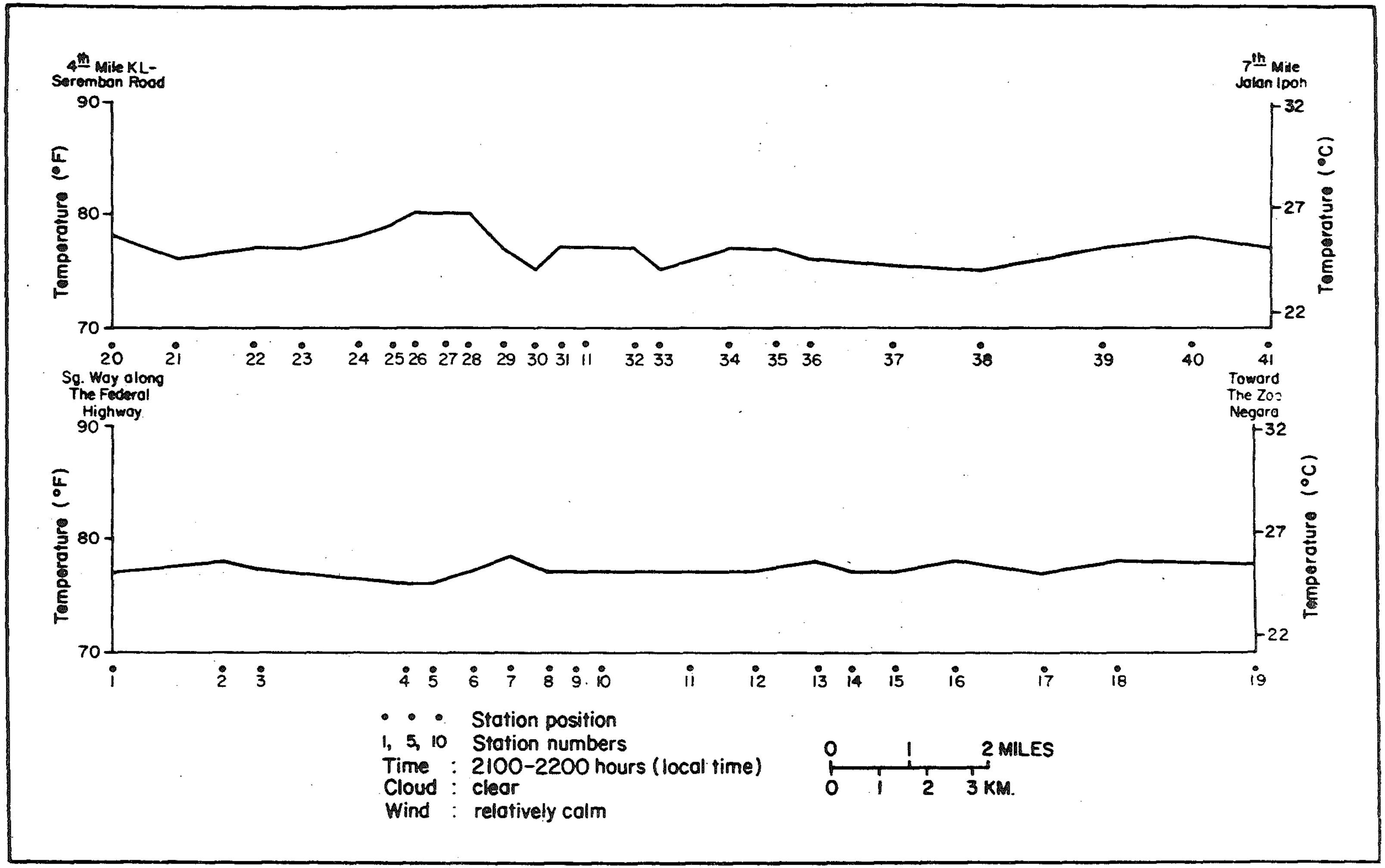


Figure 67: Temperature traverses in the Kuala Lumpur - Petaling Jaya area on 25th November, 1975 during 2100-2200 hours (L.T.) under cloudy conditions

This is expected as conditions for its genesis were rather different. Daily sunshine duration as recorded by the meteorological station at Subang was nil with daily solar radiation total of only 187.9 $mwhr/cm^2$. Rainfall of 0.76mm (0.03 inches) was also recorded for the day. Generally however although the magnitude of temperature contrasts was relatively small, Pudu shopping area, Taman Ghazali Shafie along Jalan Bangsar, and Jalan Chow Kit shopping area still emerge as areas having higher temperatures.

In summary it can be said that temperatures in the study area vary both in time and space. This is evident not only when temperatures in the built-up area are compared with those of the airport at Subang but also when all the available stations within the built-up area are compared with one another. The relative warmth of the built-up area is further illustrated by the results obtained from the night-time traverses across the study area. It was shown that under ideal condition the intensity of the heat island could be as high as 5.6°C (10°F). Under cloudy condition, however, its intensity and form are much reduced. These compare favourably with results obtained by many investigators in mid-latitude cities.

5.6 Humidity

The general effects of urbanization upon atmospheric humidity have already been noted (see Chapter 1). It appears that the general consensus is that cities may have lower atmospheric moisture levels than their surrounding rural areas, but that such differences are small (Chandler, 1962, 1965 & 1967a & b; Sasakura, 1965; Ludwig & Kealoha, 1968; Thomas, 1971; Clarke, 1972; Landsberg, 1972:

Landsberg & Maisel, 1972). This however does not necessarily mean that the city is 'drier' than the surrounding area. Both Chandler (1967a & b) and Bornstein et al (1972) have shown cases where relative humidities were lower, but absolute humidities or vapour pressures were higher in the city. Ackerman (1971) conducted a comparison of urban/rural dewpoint data for Chicago. She finds a weak seasonal, but strong diurnal variability in urban/rural differences. At night the city was more humid and it was suggested that this was due to the lack of dewfall. By day in summer the city was less humid and this was suggested to be due to the stronger vapour import by evapotranspiration or condensation in the country. In the winter, the increase in water amount released by anthropogenic activities and decrease in rural evapotranspiration and condensation was postulated to explain the city being more humid by day and night. Bornstein et al (1972) show New York City to possess a 'vapour dome'. Morning excesses about 0.2 gm^{-3} in the urban boundary layer.

Some indication of the order of humidity differences within Kuala Lumpur - Petaling Jaya and between it and the surrounding area is provided in Tables 55, 56 and 57 which show respectively the mean, maximum and minimum monthly values for the four stations. In most cases, the mean relative humidity around Petaling Jaya and Weld Reservoir is slightly lower than that at Subang despite Weld Reservoir being located on a raised ground in the city area. A comparison using the 1975 figures to keep data period for all stations on the same time basis, shows much similar results. The pattern is somewhat different, however, when Subang and the University of Malaya are compared. The greater values recorded at the University of Malaya may be attributed to altitude effect

TABLE 55

Average Mean Monthly Relative Humidity (percent) at Stations in Kuala Lumpur-Petaling Jaya, 1966-75

Station	J	F	M	A	M	J	J	A	S	O	N	D
Subang (1966-75)	82.6	81.6	82.2	85.0	84.9	84.0	83.6	83.8	84.9	84.9	87.0	86.3
Petaling Jaya (1971-75)	78.2	78.9	78.1	83.2	81.1	79.7	80.7	78.4	82.1	81.4	84.1	83.8
University of Malaya (1966-75)	82.4	79.8	82.2	85.8	85.7	85.0	83.5	84.0	84.9	86.3	87.0	83.1
Weld Reservoir (1975)	74.3	72.9	71.5	79.2	78.7	78.7	81.5	76.3	80.4	79.5	87.5	79.8

(source: Malaysian Meteorological Service and Field Measurements)

TABLE 56

Average Maximum Monthly Relative Humidity (percent) at Stations in Kuala Lumpur-Petaling Jaya, 1966-75

Station	J	F	M	A	M	J	J	A	S	O	N	D
Subang (1966-75)	97.8	97.6	97.6	97.8	97.6	97.3	97.7	97.3	97.7	97.9	98.1	98.2
Petaling Jaya (1971-75)	94.2	94.2	94.7	94.5	94.7	95.0	94.8	94.4	95.1	95.3	94.1	95.6
University of Malaya (1966-75)	96.3	95.7	96.7	96.9	96.6	96.8	96.4	96.3	96.4	96.8	96.7	96.9
Weld Reservoir (1975)	89.5	94.4	92.3	90.6	94.1	90.5	93.5	93.9	92.2	94.6	95.7	94.6

(source: Malaysian Meteorological Service and Field Measurements)

TABLE 57

Average Minimum Monthly Relative Humidity (percent) at Stations in Kuala Lumpur-Petaling Jaya, 1966-75

Station	J	F	M	A	M	J	J	A	S	O	N	D
Subang (1966-75)	55.4	52.7	53.4	58.8	60.2	60.4	59.9	59.3	59.6	59.1	63.6	62.1
Petaling Jaya (1971-75)	53.7	52.8	52.4	58.0	58.9	59.2	58.9	58.1	60.4	58.9	62.2	62.7
University of Malaya (1966-75)	57.5	53.4	54.8	60.2	62.9	63.5	62.4	61.5	62.0	62.9	63.8	63.2
Weld Reservoir (1975)	52.6	56.3	58.1	56.7	55.0	55.8	57.0	53.8	54.9	53.4	63.9	51.1

(source: Malaysian Meteorological Service and Field Measurements)

as well as the presence of a large tract of vegetation around the station. Similar patterns are observed with respect to the average maximum monthly relative humidity.

The average minimum monthly relative humidity in Table 57 shows different patterns. Subang is now being replaced by University of Malaya for having highest values although Weld Reservoir still tends to have among the lowest average minimum relative humidity in most months. The effects of altitude and the large vegetation tract around the University of Malaya station upon relative humidity have already been mentioned earlier. Comparison using the 1975 data alone does not appear to alter the patterns significantly.

Daily mean relative humidity differences at Petaling Jaya, Weld Reservoir, and University of Malaya with those of Subang graded and by month, are illustrated in Figures 68, 69 and 70 respectively. Differences for Petaling Jaya and Weld Reservoir show that in most months only less than 5.0 percent of the days have positive anomalies, while there are several months in the year with no days having any positive anomaly at all. Unlike Petaling Jaya and Weld Reservoir, the greater percentage of days having positive anomalies at the University of Malaya may be attributed, by virtue of the station altitude and site peculiarities, to the higher average minimum relative humidities which subsequently influence the values for daily averages.

The average differences in hourly relative humidity between Subang and Petaling Jaya (Subang - Petaling Jaya) for the years 1971-75 are shown in Figure 71. The small difference during 1200-1500 hours may be attributed to the correspondingly small

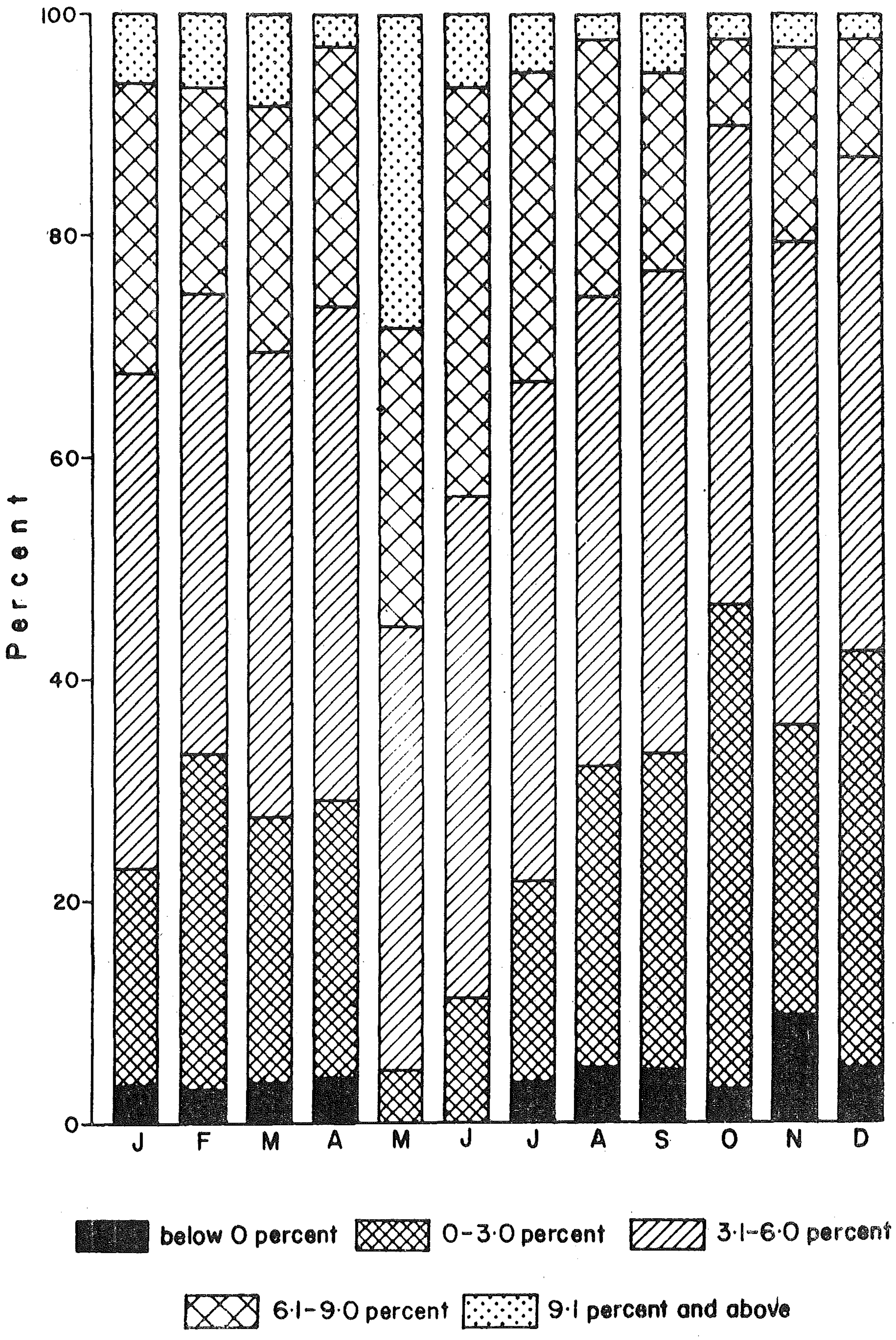


Figure 68: Differences in daily mean relative humidity, Subang - Petaling Jaya, by month, 1971-75

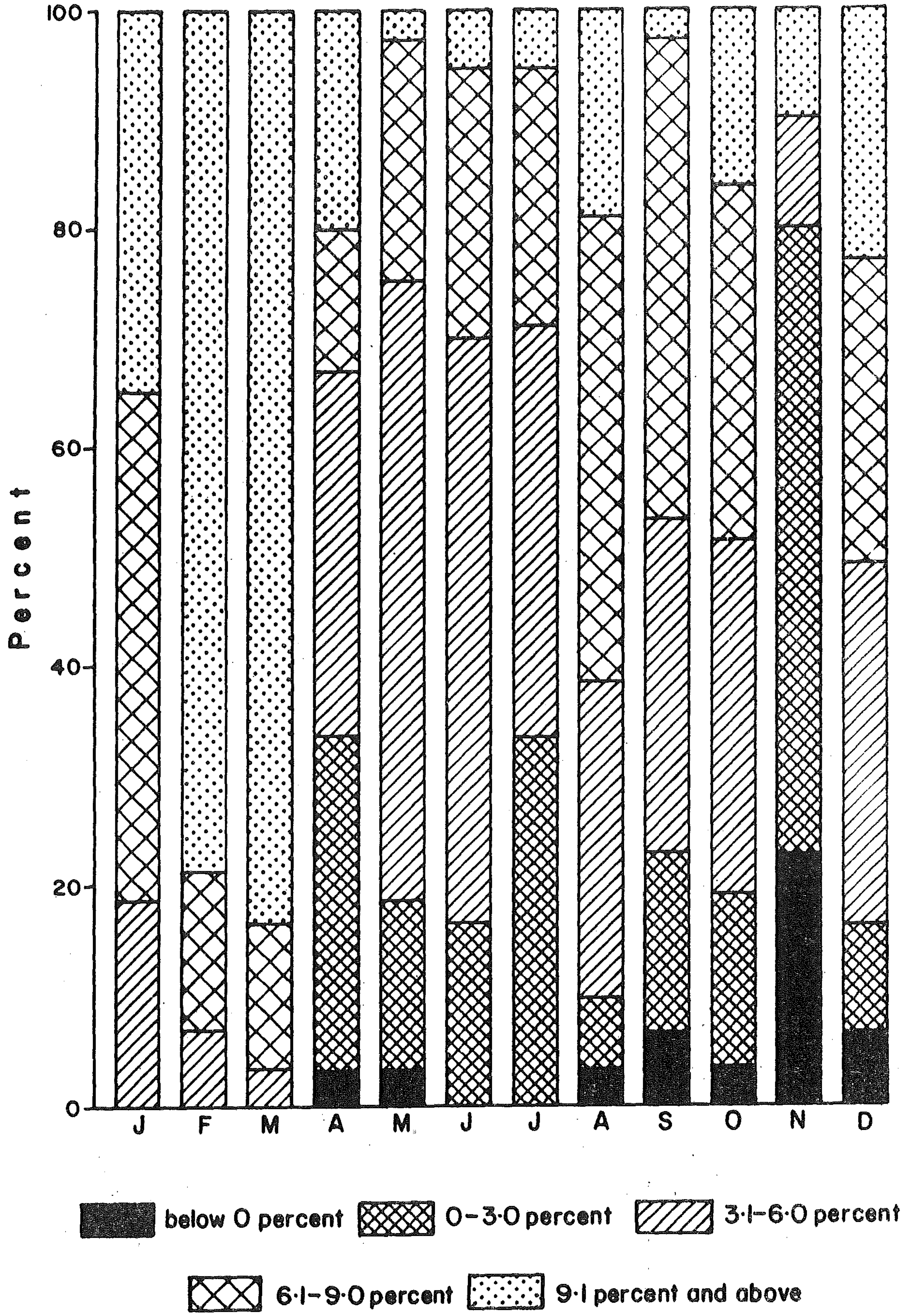


Figure 69: Differences in daily mean relative humidity, Subang - Weld Reservoir, by month, 1975

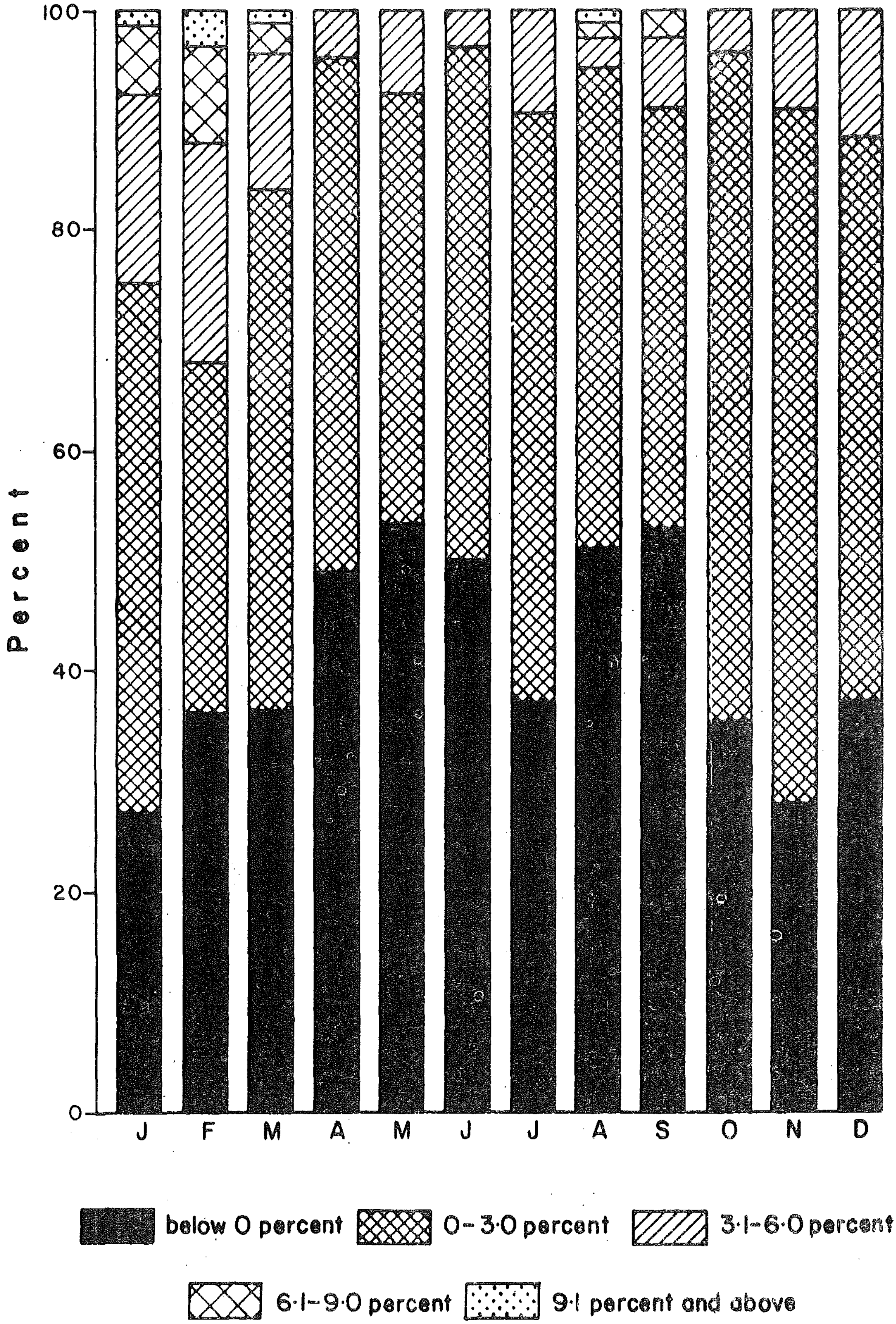


Figure 70: Differences in daily mean relative humidity, Subang - University of Malaya, by month, 1966-75

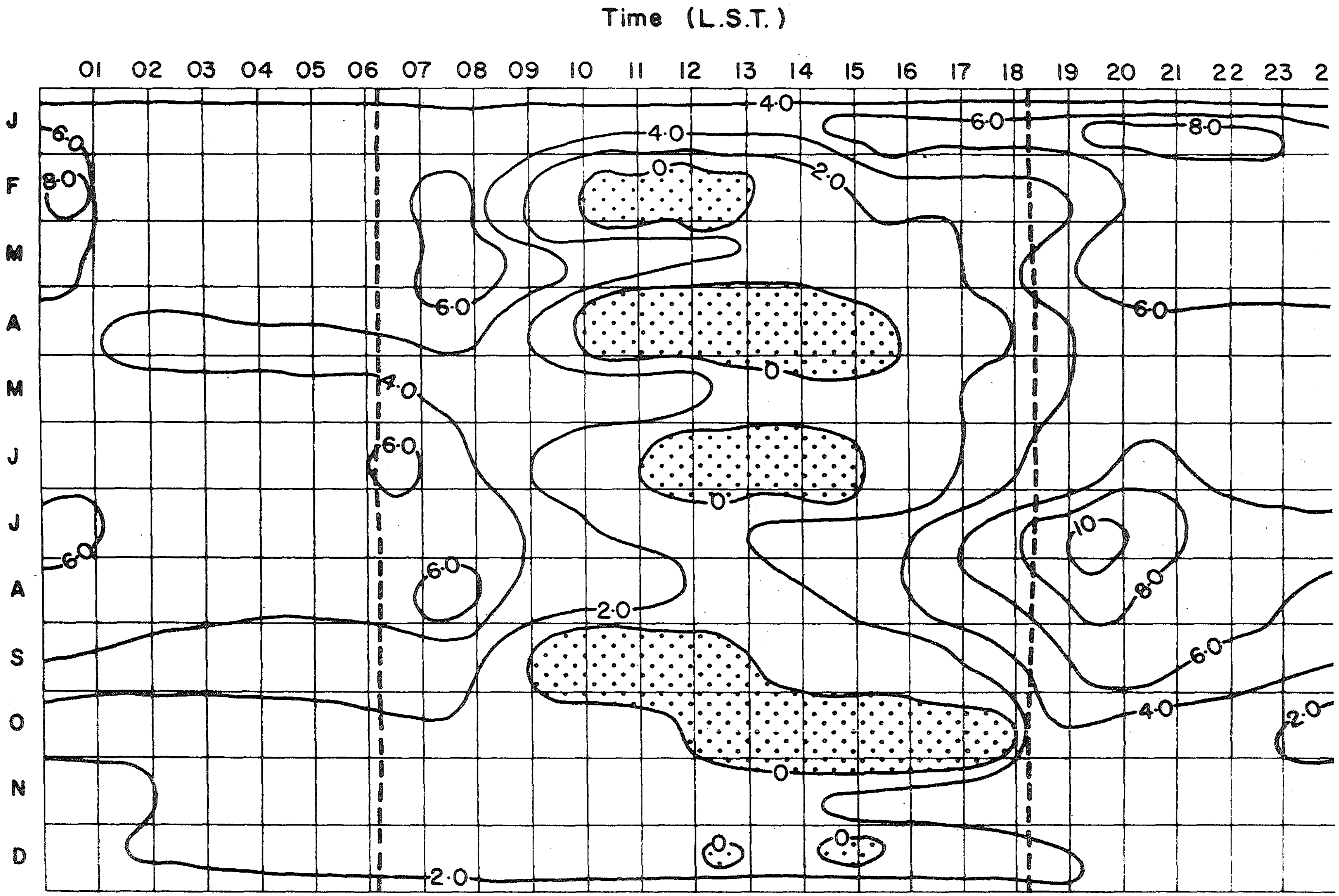


Figure 71: Differences in hourly relative humidity (in percent), Subang - Petaling Jaya, by month, 1971-75. Negative differences are stippled. Times of sunrise and sunset are shown as broken lines

temperature contrasts between the built-up area and the airport about this period which is the reverse of the situation during 2000-2300 hours when the urban heat island effect is at its maximum. The greatest difference in relative humidity at 2000 hours between Subang and Petaling Jaya may, at least in part, be attributed to this factor. A second maximum difference about 0800 hours is somewhat more difficult to understand but it could probably be due to the effect of the traffic rush in the city during this time when the atmosphere in the countryside is still relatively more humid.

Figures 72-74 show relative humidities for the same periods and weather conditions as previously described for temperatures (Figures 63-65). In Figure 72 the distribution of relative humidity is for the period 2100-2200 hours under clear and calm condition on 3rd December, 1975. Most of the commercial areas and busy thoroughfares are observed to have lower relative humidity values. Greater values are generally found in the peripheries particularly in the Lake Garden area and the adjoining Keroh Valley towards N-NE. Jalan Tuanku Abdul Rahman (a busy thoroughfare and shopping centre during the day) experiences somewhat higher relative humidity values. Reduced man's activities and traffic density along this thoroughfare at night had already been noted. The effects of the closing down of shops along Jalan Tuanku Abdul Rahman at night and those of the heat island upon relative humidity patterns are also evident in the traverses shown in Figure 73.

Similar patterns of relative humidity distribution in Kuala Lumpur - Petaling Jaya are also observed during the day as shown in Figure 74. Greater values of relative humidity are found towards the city periphery especially to the east and northwest. A sharp 'cliff' of relative humidity is noted between the commercial centre

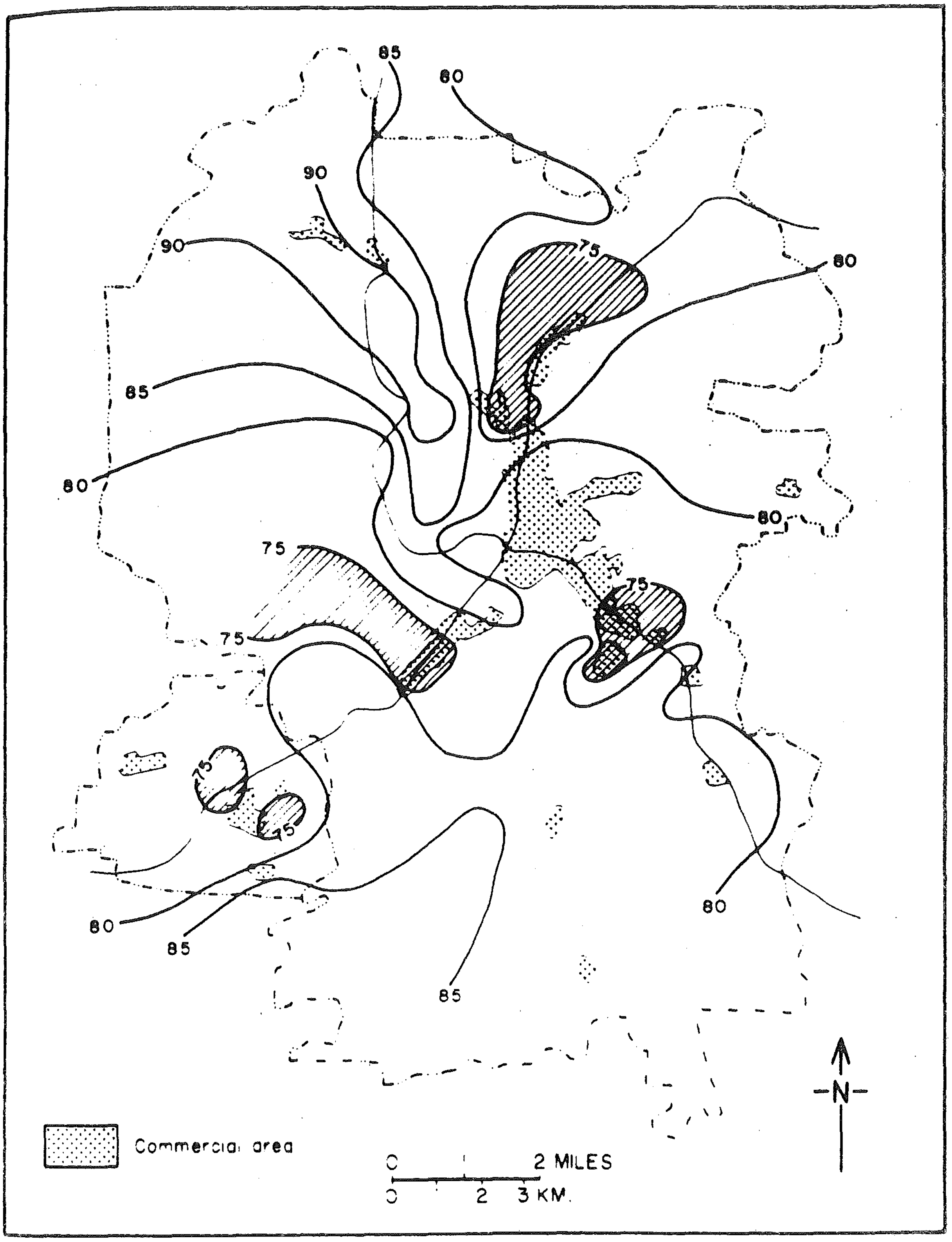


Figure 72: Distribution of relative humidity (in percent) in the Kuala Lumpur - Petaling Jaya area during 2100-2200 hours (L.T.) under calm and clear-sky conditions on 3rd December, 1975. Areas with relative humidity 75 percent and less are shaded

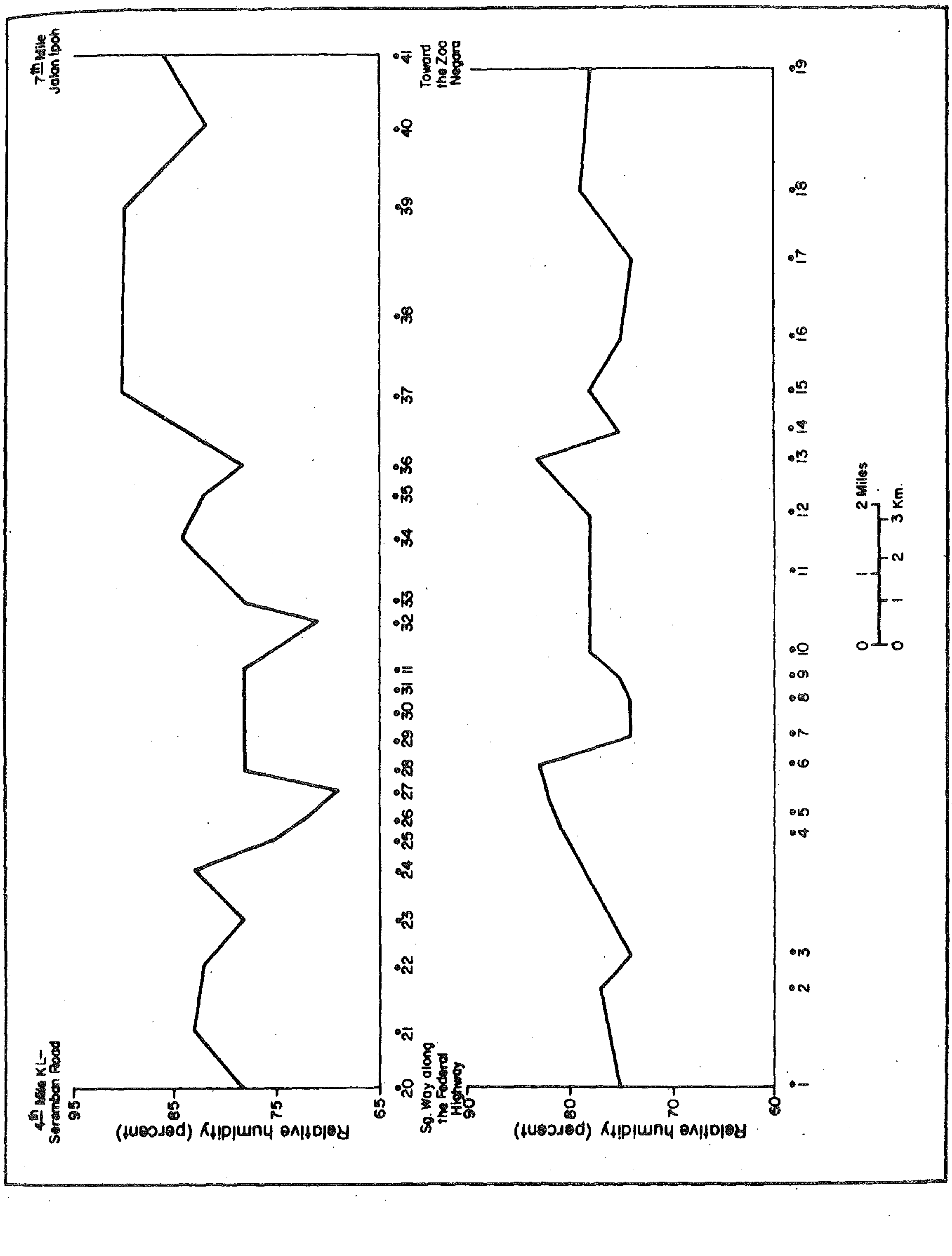


Figure 73: Relative humidity traverses in the Kuala Lumpur - Petaling Jaya area on 3rd December, 1975 during 2100-2200 hours (L.T.) under calm and clear-sky conditions

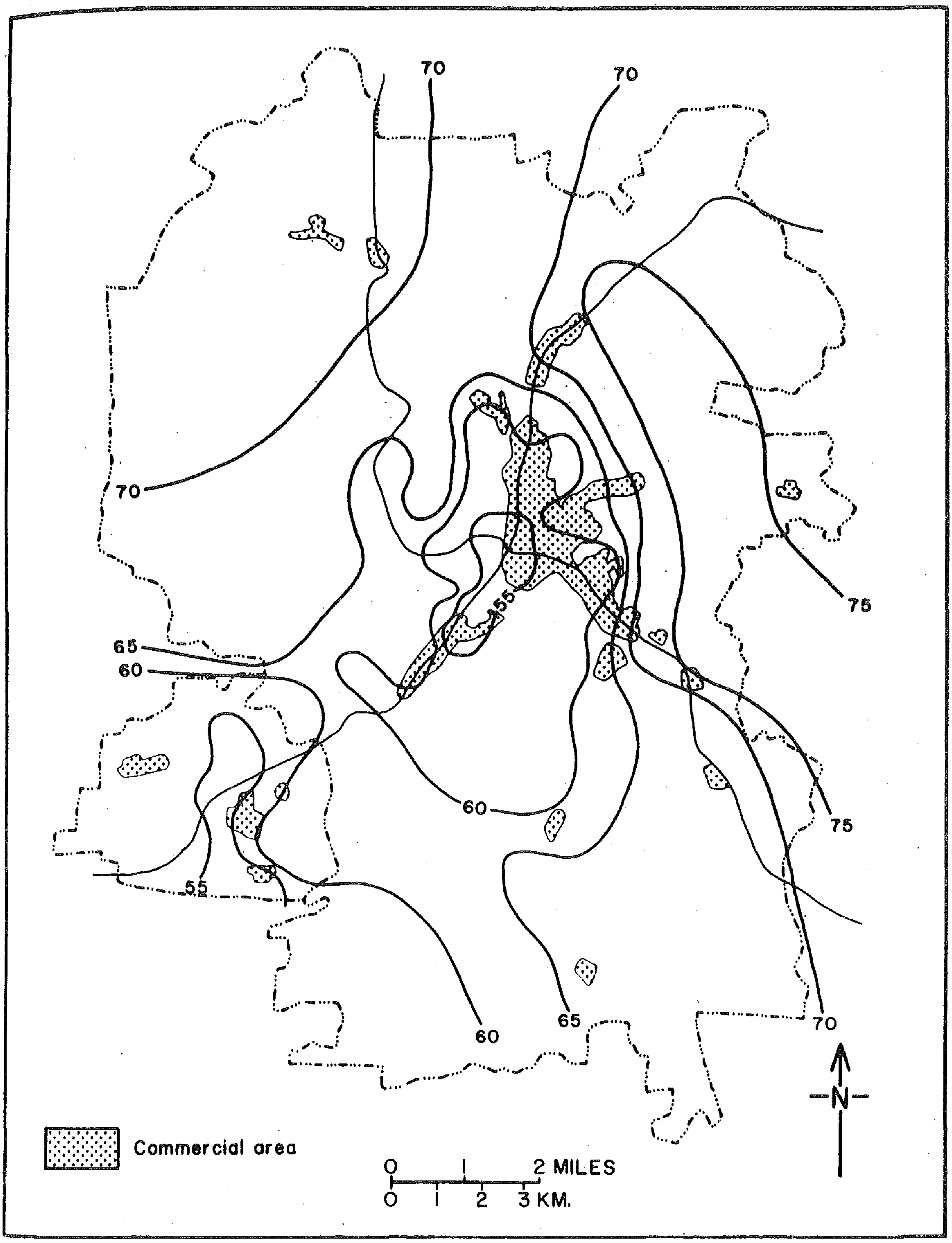


Figure 74: Distribution of relative humidity (in percent) in the Kuala Lumpur - Petaling Jaya area during 1200-1300 hours (L.T.) on 10th August, 1975

of Kuala Lumpur and area along Jalan Bangsar on the one hand and the Lake Garden on the other. Another steep gradient of relative humidity is found at the outskirt of Petaling Jaya towards the north where the latter adjoins large tract of vegetation.

5.7 Visibility

As a result of air pollution and the associated high aerosol concentrations, visibilities are lower and occurrences of fog are reported to be higher in cities than outside the metropolitan area. An example of the relationship between air pollution and visibility has been given by Georgii & Hoffman (1966), who showed that for two German cities low visibilities and high concentrations of SO_2 were highly correlated when low wind speed and low level inversions prevailed. McNulty (1968) pointed out that between 1949 and 1960 the occurrence of haze as an obstruction to visibility at New York City increased markedly as a result of increased air pollution. Holzworth & Maga (1960) analyzed data for Sacramento and Bakersfield, California and concluded that the visibility had deteriorated at both cities, supporting the belief that air pollution in California's Central Valley was increasing. In another study, Smith (1961) found that industrial areas of England, on the average, experienced low visibilities on two to three times more days than did the rural areas.

Although fog generally occurs more frequently in metropolitan areas, this is not true for many dense fogs. Chandler (1965) attributed the high frequencies of fog within a city to atmospheric pollution and relatively low wind speed, but the extra warmth of the city often prevents the thickest nocturnal fogs from reaching the densities reported in the outlying districts. Similar relationships were also detected by Brazell (1964) using London data of Shellard (1959).

Recent reports indicate that visibility in many locations has improved during the last two decades coinciding with local efforts at air pollution abatement and the substitution of oil and gas for soft coal in heat production (e.g. Bloodworth, 1953; Holzworth, 1961; Bebee, 1967). Possibly, the migration of industry to surrounding satellite towns has also had an effect (Bryson & Ross, 1972). Neiburger (1955) carried out a study of visibility trend relative to air pollution in Los Angeles for the years 1933 through 1954. The results indicated that although frequency of very good visibilities decreased markedly as the population and industry of the area grew, after 1947-48, when the control of pollutants was initiated, visibility appeared to have improved inspite of a continued increase of population and industry. This finding was later confirmed by a more recent study of the same area by Keith (1971). A similar improvement in visibility was also observed in London by Wiggett (1964), Freeman (1968) and Commins & Waller (1967) who attributed it to the enforcement of the air pollution ordinances of 1954 and 1956. Whether or not the Clean Air Act has been responsible for substantial improvements in air quality in Britain has recently been doubted by Auliciems & Burton (1973) and was noted earlier in Chapter 4.

To summarize, good visibilities decrease with increasing urbanization and industrial development. However, following substitution of oil and gas for soft coal in heat production and air pollution control efforts, visibilities in certain locations have now shown marked improvement. In the sections that follow attempts will be made to examine the extent to which air pollution in Kuala Lumpur - Petaling Jaya has affected visibility.

5.7.1 Analytical Procedures

As visibility data for Kuala Lumpur - Petaling Jaya were available only at the airport in Subang, a method due to Corfield & Newton (1968) was adopted in order to assess the possible effect of urban area as a general pollution source upon visibility.

Relative to the airport, Kuala Lumpur - Petaling Jaya lies in the sector 35°-135°. This means that if visibility data with winds in the 35°-135° sector are analyzed, a rough indication of effects of Kuala Lumpur - Petaling Jaya as a general pollution source on visibility may be obtained (Figure 75). In this analysis the implied assumption is that the wind direction at the time of the visibility observation is roughly representative of the trajectory of the air since it passes over significant pollutant sources. In order to eliminate visibility reduction due to natural causes, the observations considered were restricted to periods in which wind speeds were $0.5ms^{-1}$ (1.0 knot) and over, no precipitation was occurring, and relative humidity was less than 90 percent.

Visibility trend was examined using the method due to Holzworth & Maga (1960), and Holzworth (1961). In this method, it is considered that for any one year the total frequency of observed visibilities in all ranges is 100 percent; this is true also for the frequencies determined from the linear regression lines (Figure 76). Therefore, the initial and terminal points of the regression lines may be used to obtain the net percentage frequency changes over the span of years considered, as shown in the right portion of Figure 76. For instance, from the regression line the frequency of visibilities in the range $\geqslant$32km ($\geqslant$ 20 miles) is

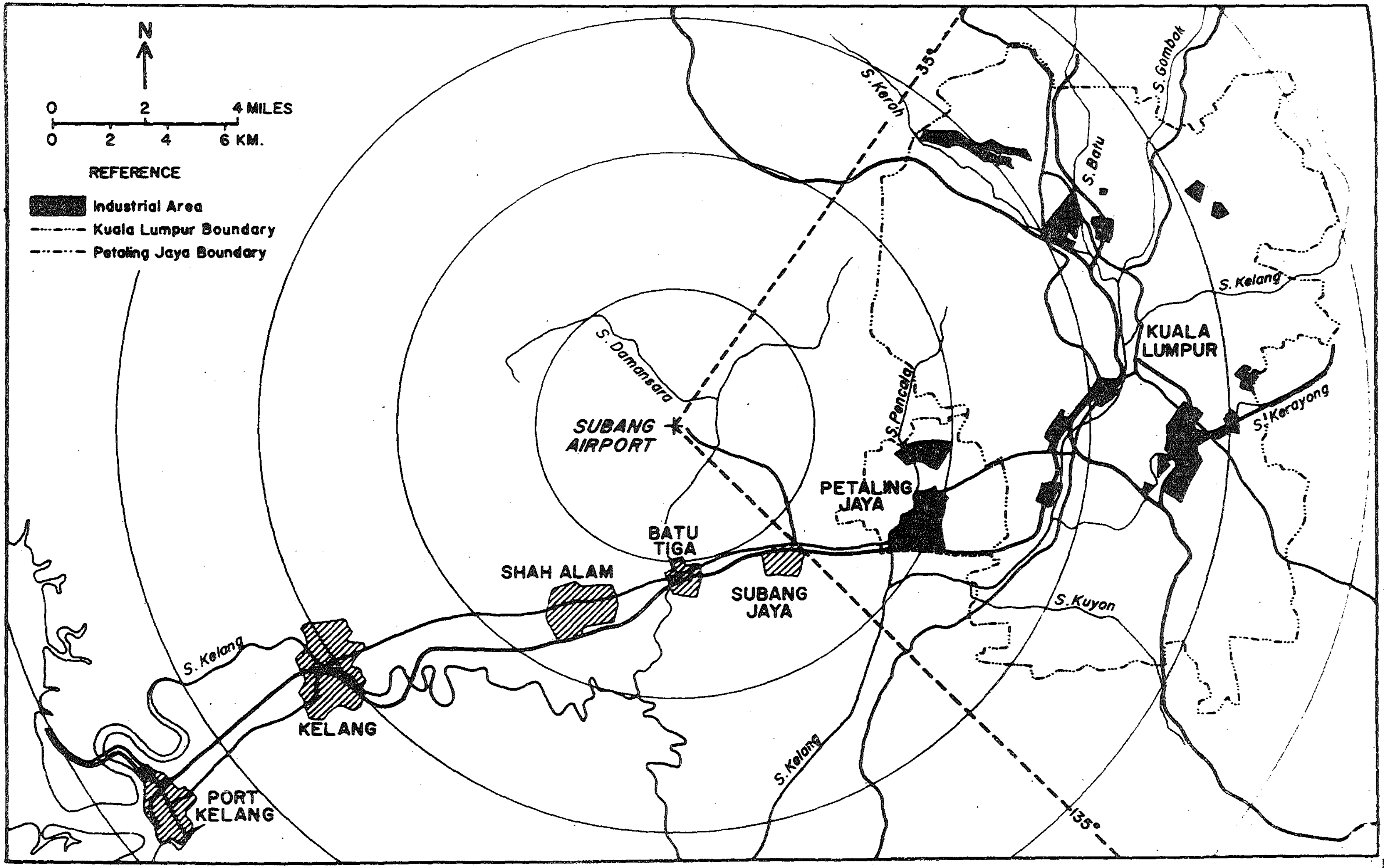


Figure 75: Kuala Lumpur - Petaling Jaya in relation to Subang Airport

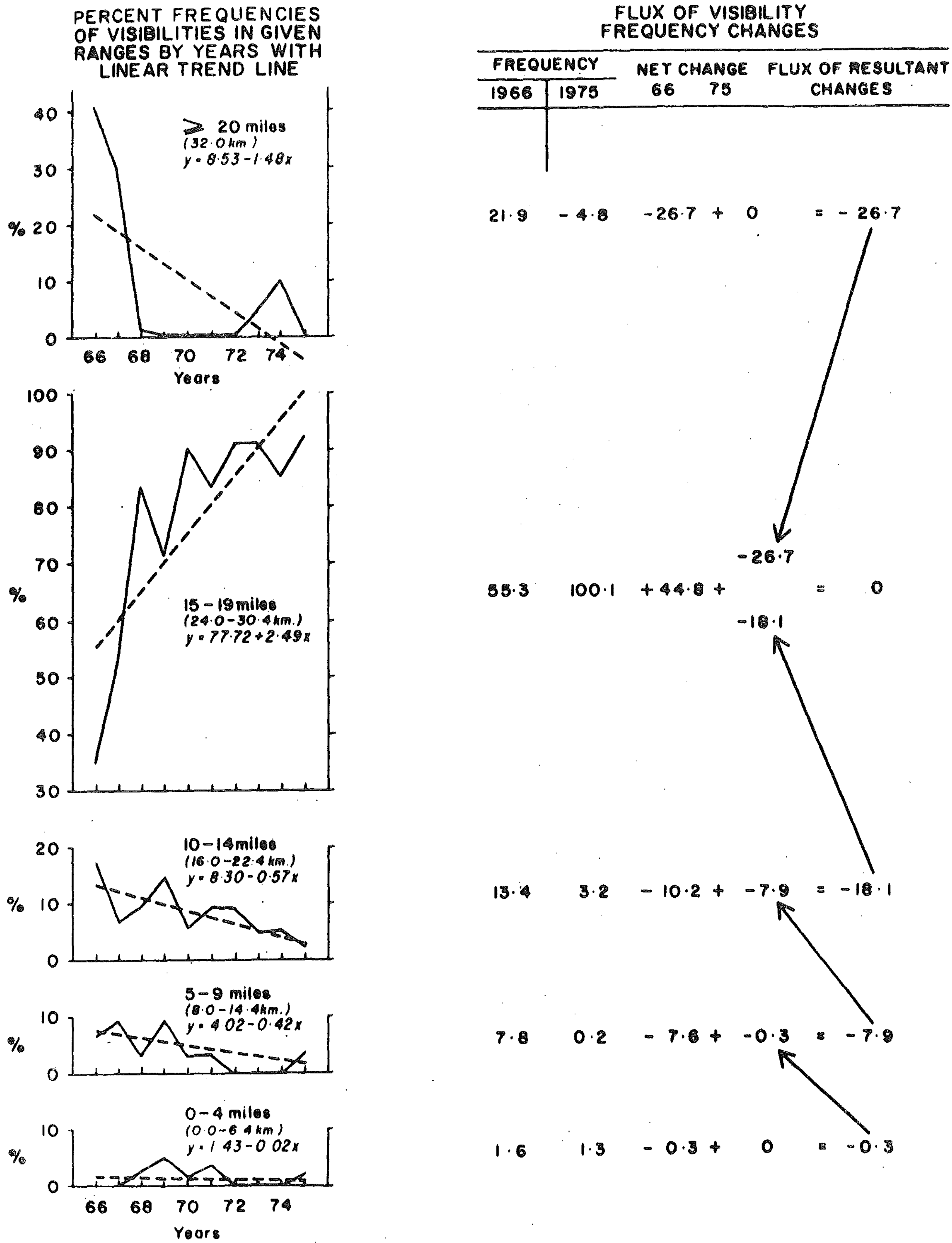


Figure 76: Percent frequencies of visibilities in given ranges by years (left) and schematic shift of visibility frequency changes (right) at Subang Airport in February, 1966-75. Linear regression lines fitted by method of least squares

21.9 percent in 1966; in 1975, it is - 4.8 percent. The net change is - 26.7 percent, and so on for the other ranges. The algebraic sum of the changes in all ranges is zero, and the decreases are compensated for by increases elsewhere. A negative net change represents a surplus of visibilities in that particular range, and a positive change, a deficit. Surpluses (net frequency decreases) in the lower visibility ranges are shifting upward to each next higher range. In each case, the amount shifted to the adjacent range is algebraically added to the net change there and the resultant value is shifted to the next range. These resultant shifts are indicated by the arrows in the right portion of Figure 76. For instance, in the lowest range, 0.0 to 6.4 km (0 to 4 miles), the net change for 1966-75 is - 0.3 percent. This surplus is shifted up to the next higher range, 8.0 to 14.4 km (5 - 9 miles), where it is added to the net change there, - 7.6 percent. The resultant is - 7.9 percent which is shifted up to the next range, 16.0 - 22.4 km (10 - 14 miles) where the net change is - 10.2 percent. The resultant change in the 16.0-to-22.4 km (10-to-14 mile) range is - 18.1 percent and this is shifted to the 24.0-to-30.4 km (15-to-19 mile) range, where the net change is +44.8 percent. The resultant change in the 16.0-to-22.4 km (10-to-14 mile) range (- 18.1 percent) together with the net change from the highest range $\geq$32.0 km ($\geq$20 miles) (- 26.7 percent) will just balance the net change in the 24.0-to-30.4 km (15-to-19 mile) of + 44.8 percent. As shown on the right side of Figure 76, the total resultant shift downward to lower visibility range is 26.7 percent, the total upward to higher ranges is 26.3 and the sum is 0.4 percent downward. In this particular case, therefore, there is a very slight trend of deteriorating visibility.

5.7.2 Visibility in Kuala Lumpur - Petaling Jaya

The percentage distribution of visibility in five ranges for the periods 1966-70 and 1971-75, and occurrences of visibility for six overlapping four-year periods with wind directions in the sector 35^{o}-135^{o} are shown in Table 58 and 59 respectively. The increase of haziness particularly in the visibility range ≥32.0km (≥ 20 miles) appeared to be consistent with the growth of built-up areas without smoke control. The Malaysian Ministry of Science, Technology and Environment has only recently been established and hitherto there has been little in the way of air pollution control measures being enforced either on industries or motor vehicles. This coupled with the steady growth of urbanization and industrial development within and around Kuala Lumpur - Petaling Jaya in the last five or six years are probably the major contributory factors in the worsening of visibilities.

Another possible alternative however would be that changes of distribution of winds according to speed or from month to month might contribute to the production of changes in the distribution of visibility. It was therefore decided to examine these relationships in greater detail. Table 60 shows the annual average distribution of visibilities for the two five-year periods for three ranges of wind speeds. Results generally confirm those presented in Tables 58 and 59 particularly in the visibility range of ≥32.0km (≥ 20 miles).

The percentage frequencies of visibilities in given ranges during the 1966-75 decade and the schematic shift of visibility frequency changes with wind directions in the sector 35^{o}-135^{o} at Subang Airport are shown in Figure 77. There are some rather large

TABLE 58

<u>Percentage Occurrences of Visibility at Subang Airport in Five Ranges for Periods 1966-70 and 1971-75 with Wind Directions in the Sector 35°-135°</u>

Period	Visibility Category					Number of occasions
	0-4 miles (0.0-6.4km)	5-9 miles (8.0-14.4km)	10-14 miles (16.0-22.4km)	15-19 miles (24.0-30.4km)	≥ 20 miles (≥32.0km)	
1966-70	1.4	6.8	15.2	71.6	5.0	3269
1971-75	1.9	0.6	14.4	77.5	0.6	1526

(source: Malaysian Meteorological Service)

TABLE 59

Percentage Occurrence of Visibility at Subang Airport in Five Ranges for Six Overlapping Periods of Five Years with Wind Directions in the Sector 35°-135°

Period	Visibility Category				
	0-4 miles (0.0-6.4km)	5-9 miles (8.0-14.4km)	10-14 miles (16.0-22.4km)	15-19 miles (24.0-30.4km)	≥20 miles (≥32.0km)
1966-70	1.4	6.8	15.2	71.6	5.0
1967-71	1.7	6.5	14.4	75.8	1.6
1968-72	1.8	5.4	14.5	78.0	0.3
1969-73	1.8	4.8	13.8	79.4	0.2
1970-74	1.7	5.0	12.9	80.0	0.4
1971-75	1.9	5.7	14.4	77.5	0.5

(source: Malaysian Meteorological Service)

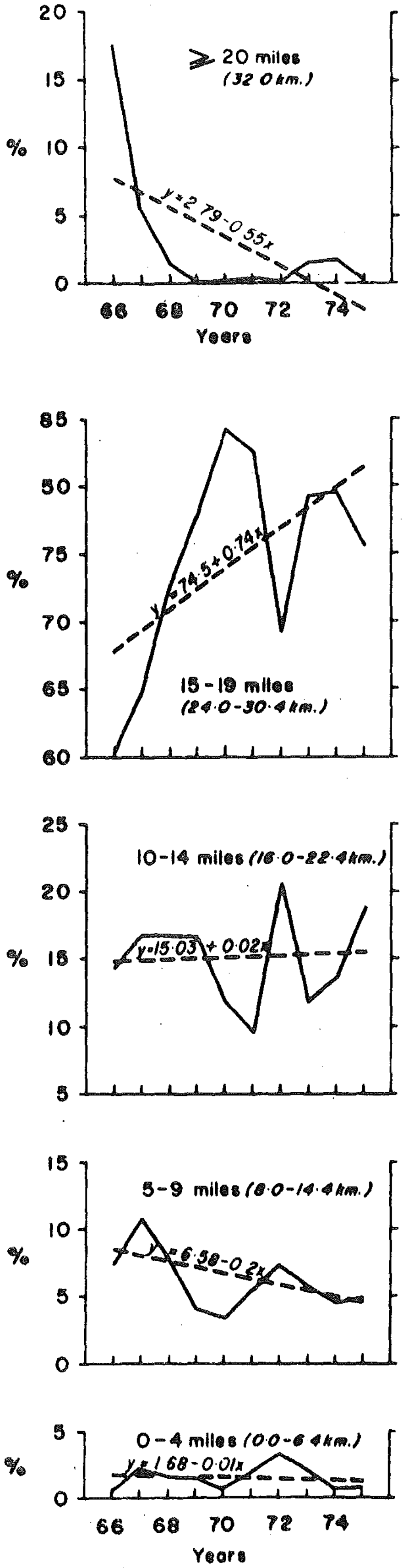
TABLE 60

Annual Percentages of Wind Speed Occurrences in the Sector 35°-135° at Subang Airport with Visibilities in Five Ranges from Periods 1966-70 and 1971-75

Wind speed	Period	Visibility Ranges					Number of occasions
		0-4 miles (0.0-6.4km)	5-9 miles (8.0-14.4km)	10-14 miles (16.0-22.4km)	15-19 miles (24.0-30.4km)	≥20 miles (≥32.0km)	
1-3 knots ($0.5-1.5\ ms^{-1}$)	1966-70 1971-75	1.0 1.4	6.3 5.9	17.6 17.3	71.0 74.8	4.1 0.6	1667 1002
4-6 knots ($2.1-3.1\ ms^{-1}$)	1966-70 1971-75	1.5 1.1	6.7 7.1	16.1 10.6	69.7 80.6	6.0 0.6	1046 350
≥7 knots (≥$3.6\ ms^{-1}$)	1966-70 1971-75	2.7 4.9	6.5 7.4	10.6 9.3	74.3 78.4	5.9 0.0	526 204
All speeds	1966-70 1971-75	1.5 1.8	6.5 6.4	16.0 14.7	71.1 76.5	4.9 0.6	3239 1556

(source: Malaysian Meteorological Service)

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE



FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES		
7·7	-2·2	-9·9	+	0	=	-9·9
67·8	81·2	+13·4	+	-9·9 -3·5	=	0
14·9	15·2	+0·3	+	-3·8	=	-3·5
8·4	4·8	-3·6	+	-0·2	=	-3·8
1·8	1·6	-0·2	+	0	=	-0·2

Figure 77: Percent frequencies of visibilities in given ranges by years (left) and schematic shift of visibility frequency changes (right) at Subang Airport for 1966-75. Linear regression lines fitted by method of least squares

variations from year to year, but as a whole the linear regression lines, fitted by the method of least squares, depict the general trend in each range fairly well. There is, however, no clear trend of improving or deteriorating visibility. The frequencies in the two lowest visibility ranges and those in the highest ranges are decreasing, while those in the 16.0-22.4 km (10-14 mile) and 24.0-30.4 km (15-19 mile) ranges are all increasing. The schematic shift of visibility frequency changes on the right side of Figure 77 nevertheless indicates that, on the average, there has been a slight trend of deteriorating visibility during the 1966-75 period amounting to 2.4 percent.

Similar analyses have been undertaken for each of the months during the 1966-75 period; the results are shown in Table 61. These indicate that the patterns are more divergent. On the average, however, there has been a deteriorating trend ranging from 0.4 percent in February to 73.0 percent in May.

5.8 Precipitation

One important meteorological consequence of atmospheric pollution is its possible influence on rainfall. Urban-induced changes in the natural precipitation are most likely to result from four potential causes. These include (1) atmospheric destablization through the existence of a well-established urban heat island (thermal effect); (2) modification of microphysical and dynamic processes in passing clouds by the addition of condensation and/or ice nuclei from industrial discharges; (3) increase in low-level mechanical turbulence caused by urban obstructions to airflow; and (4) modification of the low-level

TABLE 61

The Resultant Shift of Visibility (in percent) as Determined by the method due to Holzworth & Maga (1960) for Subang Airport, by month, 1966-75)

Trend characteristics	J	F	M	A	M	J	J	A	S	O	N	D
Total shift downward to lower visibility	27.3	26.7	36.3	27.0	74.1	6.1	14.1	12.7	0.0	20.1	31.2	34.7
Total shift upward to higher visibility	25.3	26.3	0.0	10.5	1.1	10.6	1.0	4.2	22.0	6.0	15.9	0.0
Resultant shift of visibility*	2.0↓	0.4↓	36.3↓	16.5↓	73.0↓	4.5↑	13.1↓	8.5↓	22.0↑	14.1↓	15.1↓	34.7↓

* deteriorating visibility trend is shown thus (↓)
improving visibility trend is shown thus (↑)

(source: Malaysian Meteorological Service)

atmospheric moisture content by additions from industrially generated plumes from stacks and cooling towers, along with changes in the natural evapotranspiration process within the city resulting from the larger percentage of impervious surface in central urban areas. In practice, however, all the four factors operate simultaneously making it virtually impossible to isolate one from the other. It is thus obvious from the start that any attempt to examine the effect of air pollution on rainfall will only be a qualitative assessment. This part of the present study is no exception.

Urban effects upon precipitation have been noted briefly in Chapter 1. In general, results of investigations reported so far suggest that urban precipitation enhancement is related to city size, industrial nuclei generation, and urban thermal effects. Some of these are summarized in Table 62.

Several investigators (e.g. Holzman & Thom, 1970) however have challenged the hypothesis, suggesting that there may have been some kind of observational bias. The conclusion reached in the Holzman & Thom paper concerning their analysis of the La Porte annual precipitation data is that the La Porte anomaly (Changnon, 1968) is somehow observer perpetrated, and thus 'fictional'. This conclusion has been reviewed and discussed fully by Changnon (1970). In his investigation of the effect on rainfall of a large steelworks in Port Kembla, Australia, Ogden (1969), in agreement with Holzman & Thom (1970), found no significant effect. The probable reasons for the divergent effects reported on precipitation of pollutants from steel mills have been discussed by Changnon (1971) and reviewed by Ogden (1971). In Britain, an investigation by Veryard (1958) has failed to find any significant difference in total precipitation

TABLE 62

A Summary of Studies of Urban Effects Upon Precipitation

Author(s)	Location	Max precipitation increase(%)	Max thunder-day increase(%)	Max hail-day increase(%)	Remarks
Changnon (1968)	La Porte	31.0	38.0	246.0	-
Huff & Changnon (1973)	St. Louis	15.0	25.0	153.0	-
	Cleveland	15.0	32.0	90.0	-
	Washington	9.0	47.0	100.0	-
	Baltimore	15.0	-	-	-
	Houston	17.0	10.0	430.0	-
	New Orleans	10.0	26.0	160.0	-
	Chicago	17.0	41.0	246.0	-
Khemani & Ramana Murty (1973)	Bombay	15.0	-	-	Coincided with a period of increased industrialization
Atkinson (1968)	London	5-15	-	-	-
Atkinson (1971)	London	100-120	-	-	-

that might reasonably be caused by large English conurbations while a study by Chandler (1965) on the percentage changes of precipitation in successive decades since 1881 for groups of stations in Greater London is still inconclusive.

In the sections that follow, the author is concerned only with the initial phase of research into the extent to which air pollution and urbanization processes influence regional precipitation within and around Kuala Lumpur - Petaling Jaya. It was therefore decided that analyses would be performed on all precipitation factors for which climatological data were available and which, conceivably, could be affected by urban-industrial factors. The combined weight of the evidence evolving from these varied analyses would then dictate the conclusions. Considerable reliance would be placed upon spatial pattern analyses to determine the existence (or absence) of an urban effect.

5.8.1 Analytical Procedures

The ability to evaluate, using climatological data, the effect of urban industrial pollution on rainfall is limited. Even limited success rests on the availability, which is not always met in the case of every metropolis, of (1) suitable locations which could help provide some sort of target-control contrast as is sought in the case of planned cloud seeding experiments, and (2) rainfall data, for these locations, for periods extending well into the past when the levels of pollution in the region would have been decisively less.

In the case of Kuala Lumpur - Petaling Jaya, the target area has been determined rather subjectively using surface wind data and those of the 303-metre (1000-foot) level. These indicate that the prevailing wind in the study area is from NW to S (Chapter 4). Being in the upwind region, it may reasonably be considered therefore, that the precipitation recorded at Sg. Way Estate and Bt. Jalil Estate is not modified by urban industrial pollution. On the other hand, precipitation recorded at Batu Caves Estate and D.I.D. Research Station at Ampang is likely to have been modified by pollutants picked up in course of their passage downwind over the pollution centres. On the basis of these considerations, Bt. Jalil Estate and Sg. Way Estate have been regarded as control while Bt. Caves Estate and the D.I.D. Research Station at Ampang as target (Figure 52).

Two types of precipitation analysis which followed closely those of Huff & Changnon (1972 & 1973) were also employed in the evaluation of urban effects: (1) the usual expression of station precipitation values, and (2) precipitation ratios, in which the precipitation (monthly or annual) at each station was divided by the average precipitation for the 'city' stations. For the purpose of the present study, Tangling Hospital and Weld Reservoir have been designated as the city stations. This simple normalization technique facilitated evaluation of time trends in urban industrial effects, especially during periods of region-wide departures from normal conditions. Furthermore, the ratios provide a simple index of the magnitude of any potentially urban-induced effect.

This was followed by analyses of weekday and weekend occurrences of precipitation. The rationale being, if atmospheric particulates originating from urban-industrial sources are instrumental in modifying the urban precipitation, differences between weekday and weekend rainfall are possible because of a greater output of particulates on weekdays. Evaluation was based largely upon calculations of ratios of average daily precipitation on weekdays to that on weekends. These were used to normalize differences between regional stations due to natural climatic differences.

An analysis was also made of the number of precipitation days in various intensity categories to search for supporting evidence of an urban industrial effects.

5.8.2 Urban Effects on Annual and Monthly Precipitation

Table 63 shows the mean annual rainfall during the 1953-63 and the 1964-73 periods and the percentage increase during the second period. While Bt. Jalil Estate and Sg. Way Estate in the upwind area show negative increases during the 1964-73 period, both the D.I.D. Research Station at Ampang and Batu Caves Estate record positive increases. The percentage increases however were small and not significant at the 0.05 level; t-values being respectively, 0.6576 and 1.5361.

Figure 78 shows the mean annual rainfall distribution in Kuala Lumpur - Petaling Jaya for the last decade (1964-73) and the entire sampling period (1953-73). Both maps indicate a tendency [illegible] an increase in rainfall amount towards the downwind area. This compares favourably with Chia's observation of a localized high within the downwind of Kuala Lumpur (Chia, 1968). However, although the presence of a persistently high rainfall area downwind of Kuala Lumpur - Petaling Jaya can be identified by the analysis described above, it cannot be determined whether this anomaly has resulted from urban-induced effects, topographic influences, or a combination of these two factors. The next step in the analytical process therefore was to construct precipitation ratio maps; the rationale

TABLE 63

Mean annual rainfall during 1953-63 and 1964-73 and the percentage increase during the second period. Rainfall values are given in mm.

station	Period		Percentage increase
	1953-63	1964-73	
Bt. Jalil Estate	2487.9	2451.1	-1.48
Sg. Way Estate	2582.2	2413.0	-6.55
Average Bt. Jalil and Sg. Way Estates	2535.2	2432.3	-4.06
Tangling Hospital	2596.4	2594.9	-0.06
Weld Reservoir	2481.6	2588.3	+4.29
D.I.D. Research Station, Ampang	2588.0	2666.8	+3.04
Batu Caves Estate	2612.6	2833.1	+8.44*

* The 1971 and 1972 data for Batu Caves Estate are defective and have been excluded.

(source: Drainage and Irrigation Department Malaysia)

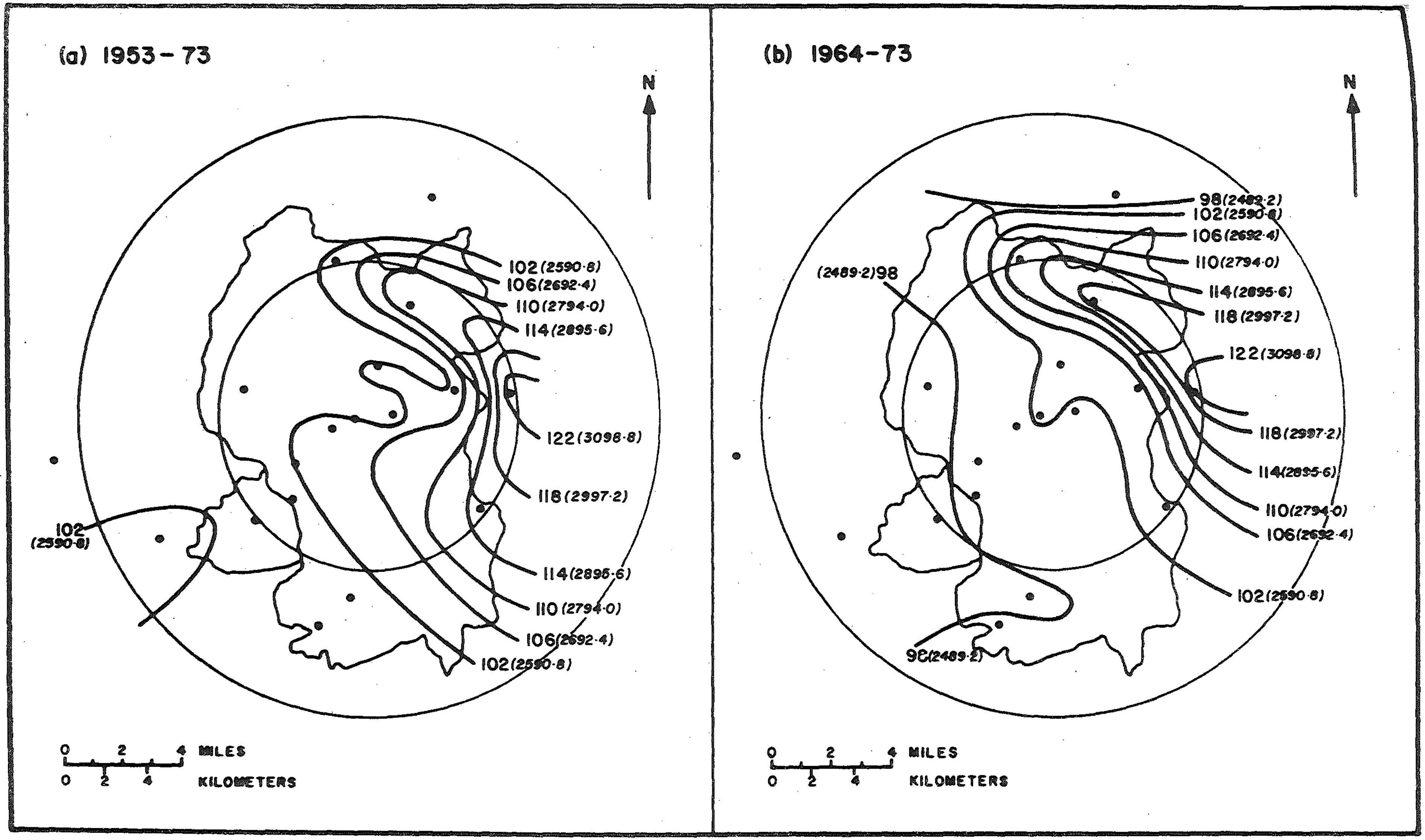


Figure 78: Annual rainfall patterns during selected periods: (a) 1953-73, (b) 1964-73. Values are given in inches with their equivalent values in mm shown in brackets

being, if urban industrial complex had any effect upon rainfall, the local anomaly should intensify with progressing time in the downwind area and be reflected accordingly in the values of the precipitation rations. Topographic-induced variations on natural climatic differences, on the other hand, are not expected to change with time (Huff & Changnon, 1972, p.827).

Figure 79 shows the annual rainfall ratios for the 1953-73 period and for the decade 1964-73. No conclusive evidence of intensification could be observed in the downwind area with progressing time with respect to the average city rainfall, i.e. the downwind/urban ratio had not increased in the more recent years (1964-73) compared with the long term average (1953-73). Although the D.I.D. Research Station at Ampang and Batu Caves Estate showed slight increases during the two periods (0.98 and 5.80 percent respectively), neither of them was significant at the 0.05 level, the t-values being 0.3950 and 0.8449 respectively. This being the case, a more likely reason for the apparent increase in the downwind area would be topographic effect and much less (if at all) the effect from urban industrial processes.

Mean rainfall amounts for the upwind, the city and the downwind areas during the entire sampling period (1953-73) and the last decade (1964-73) are given in Table 64. These indicate that although mean rainfall amounts for the city and the downwind stations exceed those of the upwind during both the 1953-73 and the 1964-73 periods, none is however significant at the 0.05 level. The t-values for both periods for the city and the downwind averages are respectively 0.7197 and 0.9650, and 0.5581 and 0.8379.

One possible explanation for an apparent increase in the rainfall averages of the downwind stations as compared with those

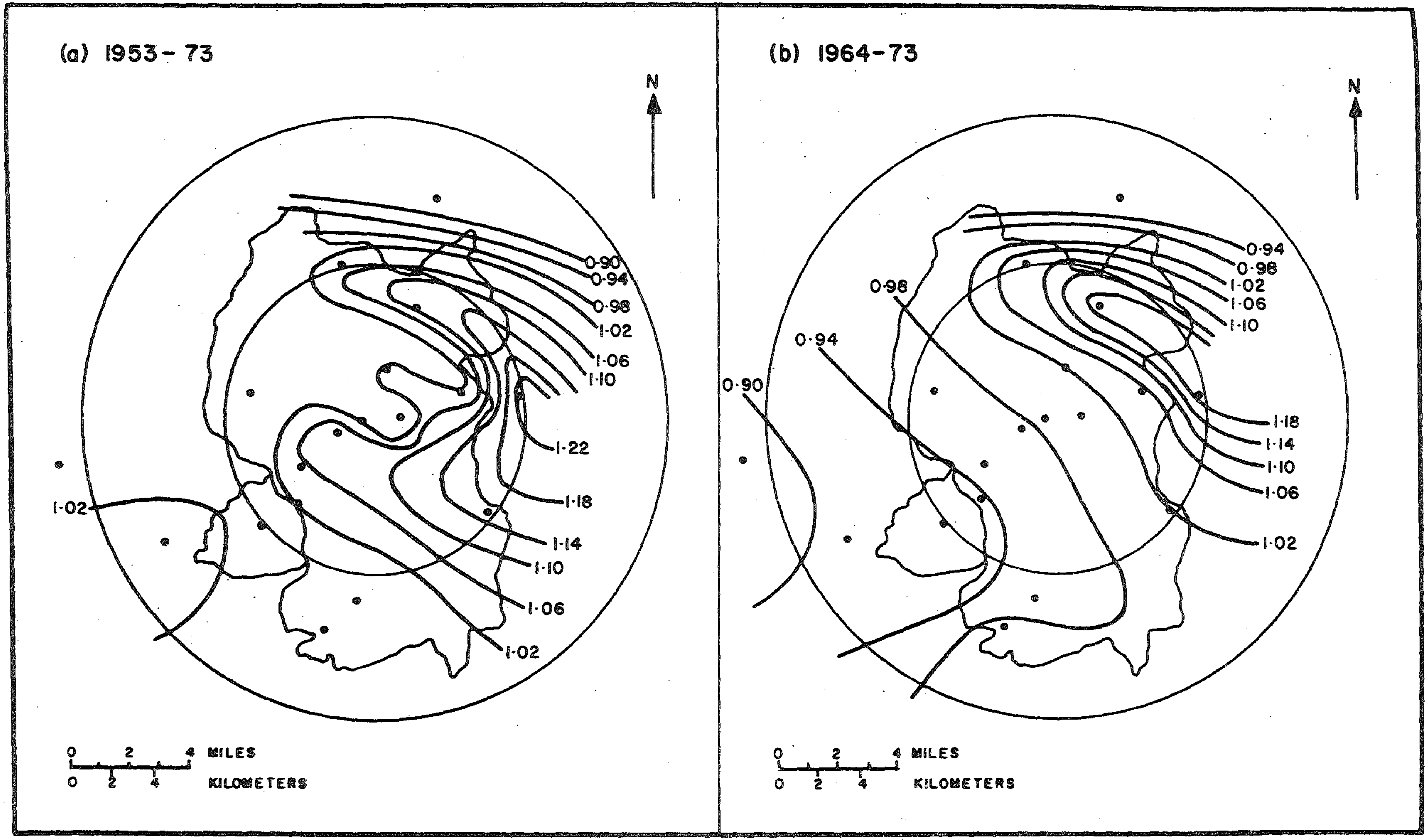


Figure 79: Annual rainfall ratio patterns for selected periods:
(a) 1953-73, (b) 1964-73

TABLE 64

Mean rainfall amount for the upwind, the city and the downwind areas during the entire sampling period (1953-73) and the last 10 years (1964-73). Rainfall values are given in mm. Percentage increase of average rainfall over that of the upwind is marked with an asterisk (*)

sampling period	Upwind average	City stations			downwind stations		
		Weld Reservoir	Tangling Hospital	Average	D.I.D. Research Stn., Ampang	Batu Caves Estate †	Average
1953-73	2486.2	2532.4 1.86*	2563.6 3.12*	2548.1 2.49*	2602.7 4.68*	2612.6 5.09*	2607.8 4.89*
1964-73	2432.3	2588.3 6.41*	2594.9 6.68*	2591.6 6.55*	2666.8 9.64*	2833.1 16.48*	2750.1 13.06*

† figures for 1971 and 1972 are excluded due to defective data

(source: Drainage and Irrigation Department Malaysia)

of the upwind (other than due to topography) is the relatively large rainfall variability from one station to the next even when these are in an area of uniform relief having similar long-term averages. This is particularly relevant in the present study because the degree of 'localness' of variability patterns is normally greater in the tropics than it is in higher latitudes (e.g. Jackson, 1975; Johnson, 1962; Sharon, 1974). The localization implies that variability patterns at nearby locations can be very different on a day-to-day basis. One point can have a heavy fall whilst a short distance away, no rain, or very little, may occur on the same day. Although it is generally accepted that differences in amount and variability pattern existing for individual days will tend to even out, it must be remembered that the above assumption ignores a key point; that much of the rain results from a small proportion of storms. For example, for the month of July, 1963 at Tangling Hospital, two days (14th and 28th) accounted for 89.75 percent of the total rainfall for the month. In September, 1965 for the same station, two days (5th and 6th) accounted for 71.14 percent of the total rainfall for the month. At Weld Reservoir, a day's rainfall (11th February, 1962) had been known to contribute as much as 72.54 percent of the month's total. This characteristic is universal and not confined to tropical areas alone. However, in temperate regions, where rain is often general over wide areas, this is comparatively less extreme. In a particular season, a few exceptionally heavy fall will produce above average rain over a wide area. Under more localized tropical rainstorms this is not the case. Hence, considerable differences in amount can persist for lengthy periods implying different patterns of variability at nearby locations.

In the present study, it is felt that this type of rainfall variability together with the effect of topography can easily cause the observed increase in the downwind of Kuala Lumpur in Figure 78 without necessarily the presence of an effective urban industrial influence. This is further supported by the lack of any definite evidence of intensification of precipitation ratios in Figure 79. It also suggests why the apparent difference in rainfall averages between the upwind and the downwind areas is not statistically significant.

5.8.3 Rainday and Weekday-weekend Relations

An analysis was made of the rainday frequencies in the Kuala Lumpur - Petaling Jaya area to see if evidence of an urban effect could be detected. As data for daily rainfall were not complete for all the years, a sample of 9 years (1956, 59, 60, 62, 63, 65, 66, 71 and 73) was used for the analysis.

Table 65 shows that for the 0.25-, 2.54-, and 12.7-mm (0.01-, 0.10-, and 0.50-inch) rain classes, the percentage excess of the downwind averages over those of the upwind are 3.58, 1.43, and 4.74 respectively. Generally, however, these percentage excess are saml1 and not significant at the 0.05 level on the Mann-Whitney test. When the city averages are compared with those of the upwind, the latter are invariably higher for all rain classes. Indeed, for both the 2.54- and 6.35-mm (0.01- and 0.25-inch) rain classes, figures for Bt. Jalil in the upwind region exceed all others.

Inspection of the weekday percentages in Table 65 indicates that with the exception of the city station average for the 6.35-mm (0.25-inch) rain class, all averages in all the other rain classes equal or exceed the expected weekday frequency of 71 percent.

TABLE 65

Point Rainfall Frequencies During Selected Years in Kuala Lumpur-Petaling Jaya

	Upwind stations			City stations			Downwind stations		
	Sg.Way Estate	Bt.Jalil Estate	Average	Tangling Hospital	Weld Reservoir	Average	D.I.D. Research Stn., Ampang	Batu Caves Estate	Average
No. of days ≥ 0.25mm	1376	1584	1480	1279	1391	1335	1636	1429	1533
Percent on weekdays*	73	71	72	73	72	72	75	85	74
No. of days ≥ 2.54mm	1150	1234	1192	971	1048	1010	1202	1215	1209
Percent on weekdays	73	71	72	71	73	72	72	74	73
No. of days ≥ 6.35mm	895	958	927	816	788	802	907	942	925
Percent on weekdays	73	73	73	70	70	70	73	73	73
No. of days ≥ 12.70mm	608	616	612	556	498	527	602	679	641
Percent on weekdays	72	73	72	72	70	71	73	74	73

* Weekdays have been defined as Mondays to Fridays. Saturday is a working day in Kuala Lumpur-Petaling Jaya; offices normally close at 1245 hours (L.T.)

(source: Drainage and Irrigation Department Malaysia)

The magnitude of the excess however is small. The average percentage occurrence on weekdays of rainfall for the upwind and the city stations for the four rain classes range from 72 to 73. These are only slightly exceeded by those of the downwind averages which range from 73 to 74 percent.

To summarize, evidence of an apparent urban effect on precipitation (if present) is not clearly evident either from the rainday frequency analysis or from the comparison of weekday-weekend frequency.

5.8.4 Heavy Rainfall Analyses

Analyses of possible urban effects on extreme rainfall events were attempted by comparing frequency distribution of daily rainfall amounts equalling or exceeding 50.8, 63.5, and 76.2 mm (2.0, 2.5, and 3.0 inches) in the urban and surrounding areas. Results are summarized in Table 66 for three rain classes in the three areas together with the percentage of the total number of raindays occurring on weekdays.

For all the three rain classes, the city and the downwind station averages always exceed those of the upwind. In the 50.8-, 63.5-, and 76.2-mm (2.0-, 2.5-, and 3.0-inch) rain classes, the percentage excess of the city averages over those of the upwind are 7.46, 17.46, and 14.75 respectively. When the upwind and downwind averages are compared, the percentage excess of the latter for the three rain classes are 5.97, 14.29, and 13.12 respectively. However, only in two rain classes (50.8- and 63.5-mm or 2.0- and 2.5-inch rain classes) that the city and the downwind averages equal or exceed the expected weekday frequency of 71 percent. Even here, the excess is small; the range of percentage occurrence on weekdays being only from 71 to 74.

TABLE 66

<u>Heavy Rainfall Frequencies During Selected Years in Kuala Lumpur-Petaling Jaya</u>

	Upwind stations			City stations			Downwind stations		
	Sg.Way Estate	Bt.Jalil Estate	Average	Tangling Hospital	Weld Reservoir	Average	D.I.D. Research Stn., Ampang	Batu Caves Estate	Average
No. of days ⩾ 50.8mm	80	82	81	106	86	96	94	99	97
Percent on weekdays*	60	65	67	73	71	72	70	72	71
No. of days ⩾ 63.5mm	37	38	38	56	44	50	49	45	47
Percent on weekdays	68	58	63	70	80	74	67	78	72
No. of days ⩾ 76.2mm	17	18	18	28	25	27	23	28	26
Percent on weekdays	71	50	61	61	80	70	65	75	69

* Weekdays have been defined as Mondays to Fridays. Saturday is a working day in Kuala Lumpur-Petaling Jaya; offices normally close at 1245 hours (L.T.)

(source: Drainage and Irrigation Department Malaysia)

It thus appears that even in the case of heavy rainfall, the evidence of urban effect on precipitation (if present) is not conclusive. Although the city and the downwind averages in the 50.8- and 63.5-mm (2.0- and 2.5-inch) rain classes exceed those of the upwind, their excess over the expected weekday frequency of 71 percent is only marginal. In the 76.2-mm (3.0-inch) rain class, none of the averages in the upwind, city and the downwind stations exceeds the expected weekday frequency of 71 percent.

5.9 Summary

The main conclusion and observations that arise from this study of the possible effects of air pollution and urbanization of climatic parameters are as follows:-

1. Like many large urban areas, Kuala Lumpur - Petaling Jaya has a considerable impact upon its local climate; the degree to which this influences climatic parameters however varies with each climatic variable. Such impacts with regard to surface wind, temperature, and relative humidity were evident not only when data within the built-up area were compared with those of the airport at Subang but also, in the case of temperature and relative humidity, through traverses across the city.

2. Under ideal condition, the intensity of the heat island can be up to 5.6°C (10°F). Generally the relative humidity is lower in the city than it is in the countryside. On the average wind speeds are greater in the built-up area at times of light winds; with strong winds however there is a decrease.

3. The evidence of possible effects of the built-up area upon solar radiation and sunshine, precipitation and visibility,

were largely inconclusive although, on the average, there was a slight trend of deteriorating visibility during the 1966-75 decade particularly in the visibility range of $\geqslant 32.0$ km ($\geqslant 20$ miles). The steady growth of urbanization and industrial development within and around Kuala Lumpur - Petaling Jaya in the last five or six years coupled with the absence of any form of smoke control measures have probably been the major contributory factors leading to the present deterioration of visibility.

4. Mean radiation value in the city area was on the average greater and that of sunshine was smaller when compared to those of Subang Airport. Although no immediate explanation could be offered for the anomaly, one possible reason for it would be that while the recording site in the city was elevated and above some of the worst city street pollution, that at the airport was gradually being affected by pollution both from aircraft exhausts and the urbanized area of Kuala Lumpur - Petaling Jaya generally.

5. Contrary to several findings elsewhere, results of analyses of mean annual and monthly solar radiation and sunshine duration by days of the week for Weld Reservoir show no difference at the 0.05 level either between Sunday and remainder of the week or between Saturday-Sunday and remainder of the week. It is believed that changes in pollution concentrations and hence their effects on incoming solar radiation are submerged by the larger and more irregular fluctuations owing to molecular scattering, reflection from and absorption by clouds and selective absorption by water vapour.

6. On the basis of mean rainfall values and the rainfall ratios, no conclusive evidence of intensification has been observed in the downwind area with respect to the average city rainfall.

Although mean rainfall amounts for the city and the downwind stations exceeded those of the upwind during both the 1953-73 and the 1964-73 periods, none of these was significant at the 0.05 level. Topographic effects and the relatively large rainfall variability among stations have been suggested as the likely explanation for the apparent increases.

7. Results of analyses of rainday frequencies likewise show no clear indication that the figures for the downwind stations are significantly greater than those of the upwind.

8. Analyses on the possible urban effects on heavy precipitation (rainfall $\geqslant$ 50.8mm or $\geqslant$ 2.0 inches) reveal no conclusive evidence. Although the city and the downwind averages in the 50.8- and 63.5-mm (2.0- and 2.5-inch) rain classes slightly exceed those of the upwind, their excess over the expected weekday frequency of 71 percent is only marginal. In the 76.2-mm (3.0-inch) rain class, none of the averages in the upwind, city and the downwind stations exceed the expected weekday frequency of 71 percent.

CHAPTER SIX

CONCLUSION

6.1 Introduction

This thesis has been concerned with an investigation into some aspects of air pollution climatology in Kuala Lumpur - Petaling Jaya. Five explicit objectives were established at the beginning of the thesis. These were: (1) to describe the local climate of Kuala Lumpur - Petaling Jaya and its likely implications on air pollution; (2) to examine the rate and nature of emissions occurring in the study area; (3) to attempt to establish the general level of concentrations of selected pollutants; (4) to investigate the influence of local weather factors on pollution concentration and dispersion; and (5) to examine the possible impact of air pollution and urbanization on climatic parameters. These objectives were approached by means of data, collected in the study area, on aspects of air pollution and climate. Data sources were varied: some were obtained from government agencies and private companies while others were collected in the field by the author. In Chapter 2, an attempt was made to establish the degree to which Kuala Lumpur - Petaling Jaya had a 'typical' tropical climate, and by examining this an assessment was made of the implications of the climate for air pollution potential. Both published information and the results of field surveys were brought together in Chapter 3 to establish an emission inventory for the Kuala Lumpur - Petaling Jaya area. Actual pollution levels for selected pollutants and climatic variables affecting them were considered in Chapter 4. The effects of air pollution and urbanization on climatic parameters were considered in Chapter 5. Major findings related to a particular chapter were summarized at the end of each. The intention here, is not primarily to repeat these summaries, but rather to assess the broader implications of the present investigation and to suggest areas of further work.

6.2 Broader Implications of the Present Study: General

It was first thought that due to data constraints and the lack of smaller time interval of sampling the conclusions reached in the study would be largely applicable to the Kuala Lumpur - Petaling Jaya area alone. However, some conclusions relating to broader scale implications are possible. For instance, in the analysis of the pollution effect of the general climate, it was shown that the Kuala Lumpur - Petaling Jaya climate had a high potential for pollution. While it is recognized that there may be some problems of interpretation with regard to results obtained using the U.S. derived forecasting technique and that comparisons between tropical and mid-latitude cities may be prejudiced by the different characteristics of weather conditions and emission properties, these probably do give a first approximation of similarities or differences. One implication of this is that as Kuala Lumpur - Petaling Jaya climate has been shown to be typical of the humid tropics which cover a large area within the confines of the Tropics of Cancer and Capricorn, this finding may well apply in the case of similar size cities experiencing the same climate type. Investigations along similar lines in other tropical cities would therefore be worthwhile.

Another more general conclusion reached in the present study was the peculiarity of variations of pollution characteristics with time. Contrary to results obtained in several mid-latitude cities, it was shown that marked seasonal variations and episodic type pollution occurrences with respect to respirable dust particulates in Kuala Lumpur were not evident. Although there was a high degree of daily variability, the concentrations generally remained within 40 - 120$\mu g/m^3$ range throughout the year. It was also shown that while the distributions of both dustfall and SO_2 appeared to be related to prevailing wind direction, and in the latter case to precipitation as well, the influence of weather factors upon respirable dust particulates was largely inconclusive. Although it was recognized that the analysis in the present case was somewhat limited because of lack of stations within Kuala Lumpur - Petaling Jaya and the need for smaller time interval of sampling, results obtained so far point to the need for extreme caution in assuming generalizations derived from studies with mid-latitude climate experience. Thus, while many of the models developed in the mid-latitude regions will be useful and applicable in the tropics, some of these may probably require verification and/or modifications.

Like many large urban areas, Kuala Lumpur - Petaling Jaya has been shown to have a considerable impact upon its local climate. The degree to which air pollution and urbanization influenced climatic parameters however varied with each climatic variable. Such impacts with regard to temperature, relative humidity and surface wind were evident not only when data within the built-up area were compared with those of the airport at Subang but also, in the case of temperatures and relative humidity, through traverses across the city. The possible effects of the built-up area upon solar radiation and sunshine, precipitation and visibility, however, were largely inconclusive although, on the average, there was a slight trend of deteriorating visibility during the 1966-75 decade particularly in the visibility range of ≯32km (≯20 miles). It must be mentioned that it was not in fact possible to separate the effects of pollution from those of other aspects of urbanization in causing urban climate variations. This awaits much more detailed investigation of heat and water balances over cities.

However, comparison with mid-latitude conditions does suggest some interesting features. For instance, the fact that heat island is strongly developed suggests that a large amount of artificial heat production is not essential for developing urban-rural differences though it may contribute elsewhere.

6.3 Broader Implications of the Present Study: Air Pollution Control Measures

The lack of data and the near absence of any organized plan of air pollution monitoring programme for Kuala Lumpur - Petaling Jaya has been noted earlier in the thesis. The networks of dustfall and SO_2 measurements in Batu Caves and Petaling Jaya respectively were no parts of any coordinated programme but had been established on an *ad hoc* basis. The present study emphasizes the need not only for a comprehensive monitoring programme but also for an integrated air quality control scheme.

One major finding of the energy survey conducted during the study was that over 87 percent of the energy use in the Kuala Lumpur - Petaling Jaya area had been from petroleum products particularly motor spirits, fuel oils and gas oils. These have all shown increases during 1972-75 period and are likely to increase further in the future following similar increases in motor vehicles and industrial activities. Such development together with an abundant supply of sunshine and radiation throughout the year will inevitably increase Los Angeles type pollution which is characteristic of a city with large number of automobiles and sunshine supply. The worst of this will be in the heart of the Kuala Lumpur City where traffic lights, numerous inefficient roundabouts and sheer volume of road transport vehicles have caused massive traffic congestions particularly during peak periods. There is no easy solution to this problem however. One possibility will be to discourage automobiles from entering the Central Business District (C.B.D.) during peak hours by imposing a kind of tax or penalty on automobiles which have less than their full load. At the time of writing, the City Hall Authority was still discussing the feasibility of applying this system in Kuala Lumpur City. One such system had already been in operation in Singapore with some success.

The selective creation of traffic-free zones, if supported by sound traffic-planning, can also substantially reduce certain pollutants within congested activity areas. In Kuala Lumpur City, there are several such congested areas one of which is the shopping complex along Jalan Tuanku Abdul Rahman. Although the net effect of the creation of traffic-free zones in Kuala Lumpur is difficult to assess, the feasibility of such an action should be given serious consideration in the future.

Other possible steps to be considered and which are likely to be useful in order to reduce vehicular congestions in the Kuala Lumpur City area are summarized in Table 67.

TABLE 67

Alternatives for Reducing Automobile Emissions

INCENTIVES

1. Express buses
2. Improvements to existing system
   a. new and expanded free parking lots
   b. development of transfer points
   c. feeder routes
   d. varied stop schedules and improved passenger amenities
   e. better transit information
3. Free transit
4. Staggered working hours
5. Computerized car pools
6. Public relation campaign

PENALTIES

1. Centre City vehicle registration
2. Higher parking charges
3. Elimination of on-street parking
4. Enforcement of existing parking regulations
5. Prohibition of daytime truck deliveries
6. Tolls levied on entering cars

TECHNICAL DEVICES

1. Change in fuels and power sources
2. Traffic control equipment
   a. computerized traffic control
   b. changed pattern and timing of lights
   c. traffic re-routing to avoid congestion
   d. metred freeways

NEW TECHNOLOGY

1. New type of buses (with improved storage facilities)
2. Dial-a-ride system
3. Automated highways
4. Guideways for personal transit
5. Monorails
6. Minicars
7. Moving beltways
8. Overpass-underpass systems
9. Use of rail right-of-ways for buses

(source: Huston & Fansmith, 1972, p.230)

Results of studies on respirable dust particulates demonstrated the importance of green areas as an effective air quality control measure. In large-scale landuse planning, green areas should separate residential areas from industrial and commercial zones. This would enable the green areas not only to filter out some of the pollution but also provide an opportunity for the atmosphere to breathe. This idea compares favourably with the 'industrial park' concept of Plater-Zyberk & Wohlers (1971). They envisage that small or low capital intensive industries generally do not have the talent to cope with control requirements, nor can they afford equipment or process changes and maintenance of an effective abatement programme. Yet in developing countries, they form a major source of employment opportunities, as indeed they are in Kuala Lumpur - Petaling Jaya, and it is their growth and development that promotes continuing industrialization and innovation. In such situation, planning agencies could encourage and restrict small operations to 'industrial parks' separated from residential areas by buffer spaces. Benefits would accrue not only from the separation of pollution sources from population, but also from common resource supply systems, common treatment and disposal systems, a common transport system, and other possibilities. Such a community of small industries would encourage communication for effective solution of environmental problems; more important, it would foster a community responsibility for the effects of industrialization while reaping many positive benefits.

For optimum effects, park areas should have no through automobile traffic. Numerous park entrances with ample parking facilities should be provided. The green areas of parks will moderate adverse climatic and air hygiene effects by reducing gusty winds, screening air pollutants, and cooling oppressive days which are prevalent in the tropics where temperatures and relative humidities are generally high. The use of green areas can also be extended to include other features within and outside the city area. Expressways and major roads, for example, could be enclosed by earth walls with shrubs to contain and filter air pollution and noise; downtown streets could be climatically and aesthetically improved by planting trees and flower beds. The urban planner can contribute to the creation and preservation of these small spaces by (a) developing regulations for requiring developers to provide land for parks or cash in lieu of the land; (b) expanding the right-of-way standards for thoroughfares; (c) instituting beautification and roadside landscaping programmes; and (d) developing tree preservation regulation.

The possibility of providing buffers around sources in the form of 'sanitary clearance zone' (Kalyuzhnyi et al, 1960) may also have a wide appeal particularly in the future development of industrial activities within and around Kuala Lumpur - Petaling Jaya. It is important however to recognize the variability of the impact of such buffers. Their value generally increases in direct proportion to the amount of source control of pollution that is effected (Voorhes et al, 1971). At low or high wind speeds a buffer zone around an uncontrolled foundry would have to be unrealistically large to satisfactorily reduce downwind ground concentrations of particulate matter.

In cases where the amounts of pollutants have far exceeded the level which is normally permitted for an area, serious considerations should be given to close down the plants concerned. In the present study, the dustfall in and around Batu Caves is a case in point. As a large proportion of the area around Batu Caves is residential and that the level of dustfall has far exceeded the standard recommended for such an area, the cement works and quarrying activities need to be stopped and wherever possible relocated. This is particularly desirable especially when Batu Caves is now becoming more important as a tourist attraction centre.

6.4 Suggestions for Further Research

As the present study has been largely exploratory in nature, it is apparent that many questions relating to detailed variations of air pollution climatology were only tentatively answered. For instance, the effect of weather factors upon air pollution dispersion clearly needs more detailed analysis. Although gross patterns of daily variation of respirable dust particulates were identified, no investigations of the variation on a smaller time scale were made. The available records were also discontinuous with many missing data. There is therefore a need to monitor not only a continuous daily pollution record in order to allow for a time series analysis but also a continuous hourly records to test the effect of periodicity at this scale. Such measurements should also be extended to include total suspended particulates, nitrogen oxides, carbon monoxide, sulphur oxides, and lead.

In the analysis of the pollution effect of the general climate, it was shown that on the basis of U.S. derived forecasting technique, the Kuala Lumpur - Petaling Jaya climate had a high potential for pollution. Some doubts however have been cast upon the direct comparability of these results with those of the mid-latitude cities. More rigorous investigations are therefore needed in order to assess the role of the mixing depth and wind speed through the mixing layer in pollution dispersion using actual measurements from tropical cities.

In the present study, air pollutant emissions had been estimated based wholly on fuels supplied to Kuala Lumpur - Petaling Jaya area. Although this could be considered adequate for a study which was exploratory in nature, a comprehensive source inventory would be necessary before multiple-source air pollution simulation models could be usefully developed for landuse planning. With an adequate source inventory, diffusion equations for each point and area source can be solved yielding composite patterns of ground-level concentrations. Although there may be large errors in the predictions for an individual hour at an individual sampling location, due to the sensitivity of the diffusion models to meandering of the wind, the frequency distribution of pollution concentrations often prove to be usefully predicted. Various simulations can then be made, adding new sources, switching fuels, and testing the effects on air quality of proposed control equipment, thus providing a tool for developing management strategies.

Effective air pollution control requires constant public awareness, public supervision and public pressure. Only a well-informed citizenry can adequately fulfill this watchdog function. This necessitates an investigation into the social correlates of air pollution: public awareness of the problem, and their willingness to do something about it (see for examples Auliciems & Dick, 1974 & 1976; Hay & Johnston, 1972). This type of information is particularly useful in developing countries such as Malaysia where, for a long time, pollution-related health effect has been considered somewhat trivial when compared to such real problems as poverty, lack of housing, crimes, unemployment, economic inflation, and lack of education.

To conclude, this thesis has shown that some types of pollution and some modifications of climate by urbanization are significant. In other parts of the world these influences have been shown to have noticeable effects on humans such that further more detailed investigations would undoubtedly be worthwhile.

REFERENCES

Ackermann, B. 1971. Moisture content of city and country air. Preprint Conference Air Pollution Meteorology, American Meteorological Society, p.154-158.

Ackermann, B. 1972. Winds in the Ekman layer over St. Louis. Preprint Conference Urban Environment and Second Conference Bio-meteorology, American Meteorological Society, p.22-27.

Aiken, S.R. & Leigh, C.H. 1975. Malaysia's emerging conurbation. Annals Association of American Geographers, v.65, n.4, p.546-563.

Angell, J.K., Pack, D.H., Hass, W.A. & Hoecker, W.H. 1968. Tetroon flights over New York City. Weather, v.23, p.184-191.

Angell, J.K., Pack, D.H., Dickson, C.R. & Hoecker, W.H. 1971. Urban influences on night-time airflow estimated from tetroon flights. Journal Applied Meteorology, v.10, p.194-204.

Angell, J.K., Pack, D.H., Machta, L., Dickson, C.R. & Hoecker, W.H. 1972. Three-dimensional air trajectories determined from tetroon flights in the planetary boundary layer of the Los Angeles Basin. Journal Applied Meteorology, v.11, p.451-471.

Angell, J.K. & Pack, D.H. 1972. The kinematics of the urban wind field and some forecast implication. Paper presented to Fourth Conference on Weather Analogue and Forecast, 17 pages.

Asmah, A. 1975. The structure of manufacturing industry in Petaling Jaya New Town, Peninsular Malaysia. Ilmu Alam, n.4, p.19-28.

Atkins, J.E. 1968. Changes in the visibility characteristics at Manchester/Ringway Airport. Meteorological Magazine, v. 97, p.172-174.

Atkinson, B.W. 1968. A preliminary examination of the possible effect of London's urban area on the distribution of thunder rainfall 1951-60. Transactions Institute of British Geographers, n.44, p.97-118.

Atkinson, B.W. 1971. The effects of an urban area on the precipitation from a moving thunderstorm. Journal Applied Meteorology, v.10, p.47-55.

Auckland Air Pollution Research Committee, 1972. Thirteenth Annual Report.

Auliciems, A. & Burton, I. 1973. Trends in smoke concentrations before and after the Clean Air Act of 1956. Atmospheric Environment, v.7, n.11, p.1063-1070.

Auliciems, A. & Dick, J.H.A. 1974. Air pollution measured by human response: a case study in Brisbane. Clean Air, v.8, p.2-4.

Auliciems, A. & Dick, J.H.A. 1976. Factors in environmental action: air pollution complaints in Brisbane. Australian Geographical Studies, v.14, n.1, p.59-67.

Aziz Ahmad, the Director-General, Factory and Machinery Department Malaysia, 1975. Personal communication.

Bach, W. 1969. Solar radiation and atmospheric turbidity, the Kettering Laboratory, University of Cincinnati, Ohio, 49 pages.

Bach, W. & Patterson, W. 1969. Heat budget studies in Greater Cincinnati. Annals Association of American Geographers, v.1, p.7-11.

Bach, W. 1971a. Atmospheric turbidity and air pollution in Greater Cincinnati. Geographical Review, v.61, n.4, p.573-594.

Bach, W. 1971b. Variation of solar attenuation with height over an urbanized area. Journal Air Pollution Control Association, v.21, n.10, p.621-628.

Bach, W. 1971c. Applications of the Gaussian Dispersion Model in air pollution control. Proceedings Hawaii Air Pollution Seminar, Honolulu, Hawaii, p.23-51.

Bach, W. 1972a. Atmospheric Pollution, McGraw Hill, 144 pages.

Bach, W. 1972b. Urban climate, air pollution, and planning. In Detwyler, T.R. & Marcus, M.G. (eds.) Urbanization and Environment, the Physical Geography of the City, Duxbury Press, p.69-96.

Bach, W. & Lennon, K. 1972. Air pollution and health at Ala Moana shopping center in Honolulu. Hawaii Medical Journal, v.31, n.2, p.104-113.

Balfour, D. & Sons, 1974. Draft Final Report of a Master Plan for Sewerage and Sewage Disposal for Kuala Lumpur and Environs, 3 volumes.

Barry, R.G. 1970. A framework for climatological research with particular reference to scale concept. Institute of British Geographers Transactions, v.49, p.61-70.

Beebe, R.G. 1967. Changes in visibility restrictions over a 20-year period. Bulletin American Meteorological Society, v.48, p.348.

Benarie, M. 1975. Modelling urban air pollution. Atmospheric Environment, v.9, n.5, p.552-553.

Bennett, I. 1965. Monthly maps of mean daily insolation for the United States. Solar Energy, v.9, p.145-158.

Berg, O.T.G. 1963. Investigation of Coalescence in Washout, Rep. 0780-01(01), Aerojet-General Corp., Downey, California.

Bezuglaya, E. Yu & Sonkin, L.R. 1971. The effect of meteorological conditions on air pollution in cities of the Soviet Union. Gidromet, p.246-256 (translated into English by Nurklik, A., Atmospheric Environment Service, Toronto).

Bierly, E.W. & Hewson, E.W. 1962. Some restrictive meteorological conditions to be considered in the design of stacks. Journal Applied Meteorology, v.1, p.383-390.

Bland, W.R. 1974. Seasonal variations in air pollution in Los Angeles County. Professional Geographer, v.26, n.3 p.277-282.

Blifford, I.H. Jr. & Meeker, G.O. 1967. A factor analysis model of large scale pollution. Atmospheric Environment, v.1, p.147-157.

Bloodworth, S.H. 1953. The decreasing importance of smoke in reducing visibilities at Atlanta, Georgia. Bulletin American Meteorological Society, v.34, p.78.

Boettger, C.M. 1961. Air pollution potential east of the Rocky Mountain: fall 1959. Bulletin American Meteorological Society, v.42, p.615-620

Booker, D.V. 1967. Elimination of 5-micron particles from the human lung. Nature, v.215, n.5096, p.30-33.

Bornstein, R.D. 1968. Observations of the urban heat island effect in New York City. Journal Applied Meteorology, v.7, p.575-582.

Bornstein, R.D., Lorenz, A. & Johnson, D.S. 1972. Recent observations of urban effects on winds and temperatures in and around New York City. Paper presented to the American Meteorological Society Conference on the Urban Environment, Philadelphia, 31st Oct. - 2nd Nov., 1972.

Bourke, W.L. 1973. Air pollution from aircraft operations at Sydney (Kingsford-Smith) airport. Clean Air, v.7, n.4, p.74-79.

Brazell, J.H. 1964. Frequency of dense and thick fog in Central London as compared with frequency in outer London. Meteorological Magazine, v.93, p.129-135.

Bringfelt, B. 1971. Important factors for the sulphur dioxide concentration in central Stockholm. Atmospheric Environment, v.5, p.949-972.

British Ministry of Health, 1954. Mortality and Morbidity during the London Fog for December, 1952, (Report on Public Health and Medical Subjects, No. 95), H.M.S.O.

British Standard Institution, 1969. Methods for the Measurement of Air Pollution: Part I Deposit Gauges, BS1747, 15 pages.

British Standard Institution, 1969. Methods for the Measurement of Air Pollution: Part IV the Lead Dioxide Method, BS1747, 16 pages.

Brooks, C.E.P. 1952. Selective annotated bibliography on urban climates. Meteorological Abstract Bibliography, v.3, p.734-773.

Brooks, C.E.P. & Mirrlees, S.T.A. 1930. Irregularities in the temperature of London. Quarterly Journal Royal Meteorological Society, v.56, p.375-388.

Brooks, E.A. 1959. An Introduction to Physical Micrometeorology, University of California Press, 253 pages.

Bryson, R.A. & Kutzbach, J.E. 1968. Air Pollution, Association of American Geographers, Commission on College Geography Washington, D.C. 20036, Resource Paper No. 2, 42 pages.

Bryson, R.A. & Ross, J.E. 1972. The climate of the city. In Urbanization and Environment by Detwyler, R., Marcus, M.G. et al, Dunbury Press, Belmont, California, p.52-68.

Bryson, R.A. & Hare, F.K. 1974. Climates of North America, In Landsberg, H.E. (ed.) World Survey of Climatology, v.11, 420 pages, Elsevier Scientific Publishing Co., Amsterdam-London-New York.

Buchan, A. 1869. Interruption in the regular rise and fall of temperature in the course of the year, as shown by observations made in Scotland during the past ten years, 1857-1866. Journal Scottish Meteorological Society, Edinburgh, New Series, v.2, p.4-15.

Byutner, E.K. & Gesina, F.A. 1963. Effective coefficient of capture of aerosol particles by rain and cloud droplets. (translated from Trudy, Proceedings Leningrad Hydrometeorological Institute, 15).

Casella & Co. undated. Model 'B' Personal Size Selecting Gravimetric Dust Sampler and Battery Charger, Instruction Leaflet 3107/TG, London, 38 pages.

Cermak, J.E. 1970. Air motion in and near cities - determination by laboratory simulation. Paper presented to the 1970 Western Resources Conference on Urban Demands on Natural Resources, p.35-56.

Chambers, L.A. 1962. Classification and extent of air pollution problems. In Stern, A.C. (ed.) Air Pollution, v.1, p.3-22.

Chander, R. 1973. 1970 Population and Housing Census of Malaysia volume 2: General Housing Tables-Towns, Villages and Local Council Area Part 5, Selangor, Kuala Lumpur, 96 pages.

Chandler, T.J. 1960. Wind as a factor of urban temperatures - a survey in northeast London. Weather, v.15, p.204-213.

Chandler, T.J. 1961. Surface effects on Leicester's heat island. East Midland Geographer, v.15, p.32-38.

Chandler, T.J. 1962. Temperature and humidity traverses across London. Weather, v.17, p.235-242.

Chandler, T.J. 1963. London climatological survey. International Journal Air Water Pollution, v.7, p.959-961.

Chandler, T.J. 1964. City growth and urban climates. Weather, v.19, p.170-171.

Chandler, T.J. 1965. The Climate of London, Hutchinson, 292 pages.

Chandler, T.J. 1967a. Night-time temperatures in relation to Leicester's urban form. Meteorological Magazine, v.96, p.244-250.

Chandler, T.J. 1967b. Absolute and relative humidity of towns. Bulletin American Meteorological Society, v.48, p.394-399.

Chandler, T.J. 1970. Urban climates: inventory and prospect. Urban Climates, W.M.O. Technical Note No. 108, Geneva, p.viii.

Changnon, S.A. 1961. Precipitation contrasts between the Chicago urban area and an offshore station in Southern Lake Michigan. Bulletin American Meteorological Society, v.42, p.1-10.

Changnon, S.A. 1962. A climatological evaluation of precipitation patterns over an urban area. In Symposium: Air Over Cities, U.S. Public Health Service, Taft Sanitary Engineering Center, Cincinnati, Ohio, Technical Report A62-5, p.37-67.

Changnon, S.A. 1968. The La Porte weather anomaly - fact or fiction? Bulletin American Meteorological Society, v.49, n.1, p.4-11.

Changnon, S.A. 1969. Recent studies of urban effects on precipitation in the United States. Bulletin American Meteorological Society, v.40, p.411-421.

Changnon, S.A. 1970. Reply. Bulletin American Meteorological Society, v.51, p.337-343.

Changnon, S.A. 1971. Comments on 'the effects on rainfall of a large steelworks'. Journal Applied Meteorology, v.10 p.165-168.

Chaudhry, F.H. & Cermak, J.E. 1971. Simulation of flow and diffusion over an urban complex. Preprint Conference Air Pollution Meteorology, American Meteorological Society, p.126-218.

Chia, L.S. 1968. An analysis of rainfall patterns in Selangor. Journal Tropical Geography, v.27, p.1-18.

Chia, L.S. 1969. Sunshine and solar radiation in Singapore. Meteorological Magazine, v.98, p.265-274.

Chia, L.S. 1970. A case study of disturbance during the northeast monsoon over Southern West Malaysia and Singapore on 9th and 10th December, 1969. Paper presented to Seminar on Synoptic Analysis and Forecasting in the Tropics of Asia and Southwest Pacific, December, Singapore.

Chia, L.S. 1973. Reliability of West Malaysia rainfall records: an objective evaluation. Journal Tropical Geography, v.36, p.1-7.

Christchurch Drainage Board, 1973. Odour and Related Studies: Bromley Sewage Purification Works, 90 pages.

Christchurch Regional Planning Authority, 1966. Air Pollution Advisory Committee Report, Department of Scientific and Industrial Research Information Series no.55, p.9-16, 39-55.

Clarke, J.F. 1964. A simple diffusion model for calculating point concentrations from multiple sources. Journal Air Pollution Control Association, v.14, p.347-352.

Clarke, J.F. 1969. Nocturnal urban boundary layer over Cincinnati, Ohio. Monthly Weather Review, v.97, p.582-589.

Clarke, J.F. 1972. Some effects of the urban structure of heat mortality. Environmental Research, v.5, p.93-104.

Clark, A.J. & Sharp, P.G. undated. Sulphur Dioxide: an Air Pollutant, Technical Committee of the National Society for Clean Air, 24 pages.

Commins, B.T. & Waller, R.E. 1967. Observations from a ten-year study of pollution at a site in the City of London. Atmospheric Environment, v.1, p.49-68.

Corfield, G.A. & Newton, W.G. 1966. A recent change in visibility characteristics at Finningley. Meteorological Magazine, v.97, p.204-209.

Cramer, H.E. 1959. A brief survey of the meteorological aspects of atmospheric pollution. Bulletin American Meteorological Society, v.40, p.165-171.

Crowley, W.P. 1968. Numerical advection experiment. Monthly Weather Review, v.96, p.1-11.

Dale, W.L. 1956. Wind and drift currents in the South China Sea. Malayan Journal Tropical Geography, v.48, p.1-31.

Dale, W.L. 1959. The rainfall of Malaya, Part I. Journal Tropical Geography, v.13, p.23-37.

Dale, W.L. 1960. The rainfall of Malaya, Part II. Journal Tropical Geography, v.14, p.11-28.

Davidson, B. 1967. A summary of the New York urban air pollution dynamics research programme. Journal Air Pollution Control Association, v.17, p.154-158.

Davis, M.L. 1968. Modelling Urban Atmospheric Temperature Profiles, unpublished Ph.D. thesis, University of Illinois, Urbana, 159 pages.

Davis, W.L. & Pearson, J.E. 1970. Modelling urban atmosphere temperature profiles. Atmospheric Environment, v.4, p.277-288.

De Boer, H.J. 1966. Attenuation of solar radiation due to air pollution in Rotterdam and its surroundings. Koninklijk Nederlands Meteorologisch Institute, Wetenschappel ijk Rapport, W.R. 66-1, de Bill, Netherlands, 36 pages.

Demuynck, M. & Dams, R. 1975. One year study of total suspended particulate matter at 14 locations in Belgium. Atmospheric Environment, v.9, n.11, p.1033-1035.

Department of Scientific & Industrial Research, 1945. Atmospheric pollution in Leicester - a scientific survey. Department of Scientific & Industrial Research Atmospheric Pollution Research Technical Paper No. 1, H.M.S.O., London.

Department of Statistics Malaysia, 1969. Census of Manufacturing Industries West Malaysia 1968, Kuala Lumpur, 628 pages.

Dickson, R.R. 1961. Meteorological factors affecting air pollution of a city. Bulletin American Meteorological Society, v.42, p.556-560.

Dirks, R.A. 1974. Urban atmosphere: warm dry envelope over St. Louis. Journal Geophysical Research, v.79, n.24, p.3473-3475.

Dixit, S.C.N., Alste, J. & Bagg, J. 1974. Measurements of airborne particulates in the Melbourne urban region. Clean Air, v.8, n.3, p.53-57.

Duckworth, F.S. & Sandberg, J.S. 1954. The effects of cities upon horizontal and vertical temperature gradients. Bulletin American Meteorological Society, v.35, p.198-207.

Duprey, R.L. 1968. Compilation of Air Pollution Factors, Durham, North Carolina.

Dronia, H. 1967. Der stadteinfluss anf den weltweiter temperatur trend. Meteorologische Abhandlugen, v.74, p.1.

East, S.J.C. 1968. Comparison of solar radiation in town and country. Cahiers de Geographie de Quebec, v.12, n.25, p.81-89.

Emslie, J.H. 1964. The reduction of solar radiation by atmospheric pollution at Toronto, Canada. Meteorological Branch Circular 4093, n.3, Canadian Department of Transport.

Facy, L. 1962. Radioactive precipitations and fallout. In Nuclear Radiation in Geophysics, Springer-Verlag, Berlin.

Fennimore, G. 1973. Air Pollution in Five Western Cities. In Van Tassel, A.J. (ed.) Our Environment: the Outlook for 1980, Lexington Books, U.S.A., p.367-389.

Findlay, B.F. & Hirt, M.S. 1969. An urban-induced meso-circulation. Atmospheric Environment, v.3, p.537-542.

Fletcher, R.D. 1945. General circulation of the tropical and equatorial atmosphere. Journal of Meteorology, v.2, n.3 p.167-174.

Flores, J.F. & Balagot, V.F. 1969. Climate of the Philippines. In Arakawa, H. (ed.) Climates of Northern and Eastern Asia, Elsevier Publishing Co., Amsterdam-London-New York, p.159-214.

Fonda, R.W., Dahms, R.F., Fralick, J.E. & Kendall, K.M. 1971. Heat islands and frost pockets in Bellingham, Washington. Bulletin American Meteorological Society, v.52, p.552-555.

Fosberg, F.R., Garnier, B.J. & Kuchler, A.W. 1961. Delimitation of the humid tropics. Geographical Review, v.51, p.333-347.

Francis, E.J. 1970. Survey of Air Pollution Trouble Spots in Metropolitan Auckland 1969-70, A report prepared for the Auckland Air Pollution Research Committee, 41 pages.

Freeman, M.M. 1968. Visibility statistics for London/Heathrow Airport. Meteorological Magazine, v.97, p.214-218.

Frenkiel, F.N. 1956. Atmospheric pollution and zoning in an urban area. Scientific Monthly, v.82, p.194-203.

Fuggle, R.F. 1971. Nocturnal Atmospheric Infrared Radiation in Montreal, Ph.D. dissertation, McGill University, Montreal, 237 pages.

Fuggle, R.F. 1972. Rural/urban variations in atmospheric counter radiation. South African Geographical Journal, v.54, p.138-144.

Fuquay, J.J. 1970. Scavenging in perspective. In Engelmann, R.J. & Slinn, W.G.N. (eds.) Precipitation Scavenging, U.S. Atomic Energy Commission, Division of Technical Information, p.1-5.

Gan, T.L. 1962. A Study of Some Heavy Rainspells on the East Coast of Malaya during the Northeast Monsoon Season, Memoirs Malayan Meteorological Service, No.6, 15 pages.

Garnett, A. 1957. Atmospheric pollution: geographical factors. In Thring, M.W. (ed.) Air Pollution, Butterworth Scientific Publication, London, 248 pages.

Garnett, A. 1967. Some climatological problems in urban geography with reference to air pollution. Transactions Institute of British Geographers, v.42, p.21-43.

George, R.E., Nevitt, J.S. & Verssen, J.A. 1972. Jet aircraft operations: impact on the air environment. Journal Air Pollution Control Association, v.22, n.7, p.507-515.

Georgii, H.W. 1970. The effect of air pollution on urban climate. Urban Climate, W.M.O. Technical Note 108, p.214-237.

Georgii, H. & Weber, E. 1964. Investigations on Tropospheric Washout, Report AFCRL-64-816, Johann Wolfgang Goethe University.

Georgii, H.W. & Hoffman, L. 1966. Assessing SO_2 enrichment as dependent on meteorological factors. Staub Reinhaltung der Luft (in English), v.26, p.511.

Gifford, F.A. & Hanna, S.R. 1973. Modelling urban air pollution. Atmospheric Environment, v.7, p.131-136.

Gifford, F.A. & Hanna, S.R. 1975. Modelling urban air pollution. Atmospheric Environment, v.9, p.267-270.

Goddard, W.B. 1971. Heat, Mass and Momentum Transfer Processes in the Atmosphere, unpublished Ph.D. dissertation, University of California, Davis, 68 pages.

Goldreich, Y. 1969. A Preliminary Study of Aspects of Johannesburg's Urban Climate, Ph.D. thesis, University of Witwatersrand, Johannesburg, 206 pages.

Goldsmith, J.R. 1962. Effects of air pollution on humans. Air Pollution, v.1, p.335-386.

Goodman, H.S. & Hicks, B.B. 1973. Particulate Concentrations in ground-level air along Australia's east coast (150°E longitude). Clean Air, v.7, n.2, p.25.

Government of Malaysia, 1969. The Investment Incentives Act, 1968, Ministry of Commerce and Industry, Kuala Lumpur.

Greenfield, S.M. 1957. Rain scavenging of radioactive particulate matter from the atmosphere. Journal of Meteorology, v.14, n.2, p.115-125.

Grimes, A. 1937. The Movement of Air Across the Equator, Memoirs of the Malayan Meteorological Service, No.2.

Grissollet, H. & Pelletier, J. 1957. La pollution atmospherique an Centre de Paris et ses relations avec quelques facteurs climatologique. La Meteorologie, 393, Quoted from

Summers, P.W. 1966. The seasonal, weekly and daily cycles of atmospheric smoke content in Central Montreal. Journal Air Pollution Control Association, v.16, p.432-438.

Gun, R. 1974. Tall buildings and urban planning. Paper presented to the Conference on Tall Buildings, Kuala Lumpur, 14 pages.

Halliday, E.C. & Ventner, G. 1971. A numerical experiment in simulating the transport of sulphur dioxide through the atmosphere. Atmospheric Environment, v.5, p.815-818.

Hameed, S. 1974. Modelling urban air pollution. Atmospheric Environment, v.8, p.555-561.

Hameed, S. 1975. Reply. Atmospheric Environment, v.9, p.270.

Hand, I.F. 1949. Atmospheric contamination over Boston. Bulletin American Meteorological Society, v.30, p.252-254.

Hanna, S.R. 1971. Simple methods of calculating dispersion from urban area sources. Paper presented to the Conference on Air Pollution Meteorology, Raleigh, North Carolina.

Hass, W.A., Hoecker, W.H., Pack, D.H. & Angell, J.K. 1967. An analysis of low-level constant volume balloon (tetroon) flights over New York City. Quarterly Journal Royal Meteorological Society, v.93, p.483-493.

Hay, J.E. & Johnston, R.J. 1972. Environmental attitudes and environmental knowledge. Proceedings 7th New Zealand Geography Conference, Hamilton, p.65-73.

Hilst, G.R. 1969. The sensitivities of air quality predictions to input errors and uncertainties. Paper presented to the NAPCA Symposium on Multiple Source Urban Diffusion Models, Chapel Hill, North Carolina.

Holzman, B.G. & Thom, H.C.S. 1970. The La Porte precipitation anomaly. Bulletin American Meteorological Society, v.51, p.335-337.

Holzworth, G.C. 1961. Some effects of air pollution on visibility in and near cities. In Symposium: Air Over Cities, U.S. Public Health Service, Taft Sanitary Engineering Centre, Cincinnati, Ohio, Technical Report, A62-5, p.69-88.

Holzworth, G.C. 1962. A study of air pollution potential for the Western United States. Journal Applied Meteorology, v.1, p.366-382.

Holzworth, G.C. 1964. Estimates of mean maximum mixing depths in the contiguous United States. Monthly Weather Review, v.92, p.235-240.

Holzworth, G.C. 1967. Mixing depths, wind speeds and air pollution potential for selected locations in the United States. Journal Applied Meteorology, v.6, p.1039-1044.

Holzworth, G.C. 1969. Large-scale weather influences on community air pollution potential in the United States. Journal Air Pollution Control Association, v.19, p.248-254.

Holzworth, G.C. & Maga, J.A. 1960. A method for analyzing the trend in visibility. Journal Air Pollution Control Association, v.10, p.430-436.

Howard, L. 1818. The Climate of London, First edition.

Howard, L. 1833. The Climate of London, Second edition.

Howard, L. 1833. The Climate of London Deduced from Meteorological Observations, Harvey & Denton, London, Third edition.

Huff, F.A. & Changnon, S.A. 1972. Climatological assessment of urban effects on precipitation at St. Louis. Journal Applied Meteorology, v.11, p.823-842.

Huff, F.A. & Changnon, S.A. 1973. Precipitation modification by major urban areas. Bulletin American Meteorological Society, v.54, p.1220-1232.

Huston, J.S. & Fansmith, S.J. 1972. Controlling the urban traffic environment. Preprint Conference on Urban Environment and Second Conference on Biometeorology, American Meteorological Society, Philadelphia, Oct. 31 - Nov. 2, 1972, p.229-234.

Hutcheon, R.J., Johnson, R.H., Lowry, W.P., Black, C.H. & Hadley, D. 1967. Observations of the urban heat island in a small city. Bulletin American Meteorological Society, v.48, p.7-9.

Jackson, I.J. 1975. Local differences in the patterns of variability of tropical rainfall: some characteristics and implications. Paper presented to the Australasian Conference on Climate and Climatic Change, Monash, 7th - 12th December, 1975.

Jacobson, J.S. & Salottolo, G.D. 1975. Photochemical oxidants in the New York-New Jersey Metropolitan area. Atmospheric Environment, v.9, p.321-322.

John, I.G. 1949. The Properties of the Upper Air Over Singapore, Memoirs Malayan Meteorological Service, No.4.

Johnson, D.H. 1962. Rain in East Africa. Quarterly Journal Royal Meteorological Society, v.88, p.1-12.

Johnson, W.B., Ludwig, F.L. & Moon, A.E. 1969. Development of a practical multipurpose urban diffusion model for carbon monoxide. Paper presented to the NAPCA Symposium: Multiple-source Urban Diffusion Models, Chapel Hill, North Carolina.

Jones, R. 1975. More cars but less driving on our roads. The New Straits Times, September, 19, p.6.

Jones, P.M. & Wilson, C.B. 1968. Windflow in an urban area: a comparison of full scale and model flows. Building Science, v.3, p.31-40.

Kalyuzhnyi, D.N., Kostovetskii, Ya.la, Davydov, S.A. & Aksel'rod, M.B. 1960. Effectiveness of sanitary clearance zones between industrial enterprises and residential quarters. In Survey of U.S.S.R. Literature on Air Pollution and Related Occupational Diseases, translation by Levine, B.S., U.S. Department of Commerce, Washington, D.C., v.4, p.179-183.

Katz, M. 1963. Air pollution in Canada - current status report. American Journal of Public Health, v.53, p.173-184.

Kawamura, T. 1964. Analysis of the temperature distribution in Kumagaya City - a typical example of the urban climate of a small city. Geographical Review of Japan, v.27, p.243-254.

Keith, R.W. 1971. Downtown Los Angeles noon visibility trends, 1933-1969. Preprint Conference on Air Pollution Meteorology, Raleigh, April 5-9, 1971, p.85-91.

Kennedy, A.M., Peet, N.J., Marlow, J.C. & Brown, K.J. 1974. Survey of Fuel, Energy and Air Pollution in the Christchurch Urban Area (1966-73), Department of Chemical Engineering, University of Canterbury, Christchurch, New Zealand, 71 pages.

Khemani, L.T. & Ramana Murty, B.H.V. 1973. Rainfall variations in an urban industrial region. Journal Applied Meteorology, v.12, p.187-194.

Kirov, N.Y. 1968. Refuse disposal - a growing world problem. Clean Air, v.2, p.7-12.

Kleinman, M.T., Kneip, T.J. & Eisenbud, M. 1976. Seasonal patterns of airborne particulate concentrations in New York City. Atmospheric Environment, v.10, n.1, p.9-12.

Kneip, T.J., Eisenbud, M., Strehlow, C.D. & Freudenthal, P.C. 1970. Airborne particulates in New York City. Journal Air Pollution Control Association, v.20, n.3, p.144-149.

Kopec, R.J. 1970. Further observations of the urban heat island in a small city. Bulletin American Meteorological Society, v.51, p.602-606.

Kratzer, P.A. 1957. Das Stadklima, Die Wissenshaft, v.90, Brunswick, Vieweg, 184 pages.

Kuhn, E. 1959. Planning and the city's climate. Landscape, v.8, p.21-23.

Landsberg, H.E. 1956. The climate of towns. In Thomas, W.L. (ed.) Man's Role in Changing the Face of the Earth, Chicago, p.584-606.

Landsberg, H.E. 1960. Physical Climatology, 2nd revised edition, Du Bois, Penn. Gray Printing Co., 446 pages.

Landsberg, H.E. 1970. Micrometeorological temperature differentiation through urbanization. Urban Climates, W.M.O. Technical Note 108, p.129-136.

Landsberg, H.E. 1972. Inadvertant Atmospheric Modification through Urbanization, Technical Note No. BN 741, Institute Fluid Dynamics Applied Mathematics, University Maryland, 73 pages.

Landsberg, H.E. 1974. Inadvertant atmospheric modification through urbanization. In Hess, W.N. (ed.) Weather and Climate Modification, John Wiley & Sons, p.726-764.

Landsberg, H.E. & Maisel, T.N. 1972. Micrometeorological observations in an area of urban growth. Boundary-Layer Meteorology, v.2, p.365-370.

Lawrence, E.N. 1968. Changes in air temperature at Manchester airport. Meteorological Magazine, v.97, p.43-51.

Leahey, D.M. 1969. An Urban Heat Island Model, Report TR-69-11, Department of Meteorology and Oceanography, New York University, 70 pages.

Ledbetter, J.O. 1972. Air Pollution Part A: Analysis, Marcel Dekker Inc., 424 pages.

Lee, H.S. 1975. Urban services in the City of Kuala Lumpur with particular emphasis on solid waste disposal aspect (unpublished typescript), City Hall Kuala Lumpur.

Lettau, H.H. 1970. Physical and meteorological basis for mathematical models of urban diffusion processes. In Stern, A.C. (ed.) Proceedings of Symposium on Multiple-source Urban Diffusion Models, U.S. Environmental Protection Agency, Air Pollution Central Office Research Triangle Park, North Carolina, p.2.1 - 1.26.

Lim, C.Y. 1969. A Survey of Malaysian Industrial Estates, First National City Bank, Asia Press, Kuala Lumpur, p.23.

Lockwood, J.G. 1967. Probable maximum 24-hour precipitation over Malaya by statistical methods. Meteorological Magazine, v.96, p.11-19.

Lockwood, J.G. 1974. World Climatology: An Environmental Approach, Edward Arnold, 330 pages.

Lodge, J.P. Jr. 1962. Recent developments in the chemistry of urban atmospheres. In Symposium: Air Over Cities, Sanitary Engineering Center Technical Report A62-5, Cincinnati, Ohio, p.31-36.

Ludwig, F.L. 1967. Urban Climatological Studies, Interim Report No. 1, Contract OCD-PS-64-201, Stanford Research Institute, Menlo Park, California (AD 657248).

Ludwig, F.L. & Kealoha, J.H.S. 1968. Urban Climatological Studies, Final Report, Contract OCD-DAHC-20-67-C-0136, Stanford Research Institute, Menlo Park, California.

Lyons, W.A. 1971. Mesoscale transport of pollutants in the Chicago area as affected by land and lake breezes. In England, H.M. & Beery, W.T. (eds.) Proceedings of the 2nd International Clean Air Congress, Academic Press, p.973-978.

Malaysian National Electricity Board, undated. Annual Report 1972, MAS Sdn. Bhd.

Malkus, J.S. & Stern, M.E. 1953. The flow of a stable atmosphere over a heated island, Part I. Journal of Meteorology, v.10, p.30-41.

Manley, G. 1944. Topographical features and the climate of Great Britain. Geographical Journal, v.103, p.241-263.

Marshall, W.A.L. 1952. A Century of London Weather, H.M.S.O.

Marshall, J.S. & Palmer, W.McK. 1948. The distribution of raindrops with size. Journal of Meteorology, v.5, p.165-166.

Mason, B.J. 1957. The Physics of Clouds, Oxford University Press, London.

Masters, G.M. 1974. Introduction to Environmental Science and Technology, John Wiley & Sons, 404 pages.

Mateer, C.L. 1961. Note on the effect of the weekly cycle of air pollution on solar radiation at Toronto. International Journal Air Water Pollution, v.4, p.52-54.

McBoyle, G.R. 1969. Some Deductions on the Effect of the Local Environment on the Climate of Aberdeen, Ph.D. thesis, Geography Department, University of Aberdeen, Scotland.

McCormick, R.A. 1962. Air pollution - some meteorological aspects. Weatherwise, v.15, p.229-238.

McCormick, R.A. & Baulch, D.M. 1962. The variation with height of the dust loading over a city as determined from the atmospheric turbidity. Journal Air Pollution Control Association, v.12, p.492-496.

McCormick, R.A. & Kurfis, K.R. 1966. Vertical diffusion of aerosols over a city. Quarterly Journal Royal Meteorological Society, v.92, p.393-396.

McDermott, W. 1961. Air pollution and public health. Scientific American, v.205, p.49-57.

McDonald, J.E. 1963. Rain washout of partially wettable insoluable particles. Journal Geophysics Research, v.68, p.4993-5003.

McElroy, J.L. 1971. An Experimental and Numerical Investigation of the Nocturnal Heat Island over Columbus, Ohio, unpublished Ph.D. thesis, The Pennsylvania State University, 132 pages.

McNulty, R.P. 1968. The effect of air pollutants on visibility in fog and haze at New York City. Atmospheric Environment, v.2, p.625-628.

McTaggart, W.D. 1972. Industrialization in West Malaysia, 1968, Occasional Paper No. 2 (Tempe, Arizona: Center for Asian Studies, Arizona State University, 1972.)

Middleton, W.E.K. & Miller, F.G. 1936. Temperature profiles in Toronto. Royal Astronomical Society Journal, v.30, p.265-272.

Miller, M.E. & Holzworth, G.C. 1967. An atmospheric diffusion model for metropolitan areas. Journal Air Pollution Control Association, v.17, p.46-50.

Miller, M.E. & Niemeyer, L.E. 1963. Air pollution potential forecast - a year's experience. Journal Air Pollution Control Association, v.17, p.205-210.

Mitchell, J.M. Jr. 1953. On the causes of instrumentally observed secular temperature trends. Journal of Meteorology, v.10, p.244-261.

Mitchell, J.M. Jr. 1961. The temperature of cities. Weatherwise, v.14, p.224-229.

Mitchell, J.M. Jr. 1962. The thermal climate of cities. Symposium: Air Over Cities, U.S. Public Health Service, Taft Sanitary Engineering Center, Cincinnati, Ohio, Technical Report A62-5, p.131-145.

Molenkamp, C.R. 1968. Accuracy of finite-difference methods applied to the advection equation. Journal Applied Meteorology, v.7, p.160-167.

Monteith, J.L. 1966. Local differences in the attenuation of solar radiation over Britain. Quarterly Journal Royal Meteorological Society, v.92, n.392, p.254-267.

Moses, H. 1969. Mathematical urban air pollution models. Paper presented to the 62nd. Annual Meeting of the Air Pollution Control Association (APCA).

Munn, R.E. 1961. The Interpretation of Air Pollution Data, with Examples from Vancouver, CIR-3454, TEC-351, Meteorological Branch, Department of Transport, Canada.

Munn, R.E. 1968. Annotated bibliography for air pollution meteorology. Journal Air Pollution Control Association, v.18, p.449-453.

Munn, R.E. 1970. Airflow in urban areas. Urban Climates, W.M.O. Technical Note No. 108, Geneva, p.15-39.

Munn, R.E. 1973a. Modern applications of meteorology to air pollution control. Journal Air Pollution Control Association, Quebec Section, 9 pages.

Munn, R.E. 1973b. A study of suspended particulate air pollution at two locations in Toronto, Canada. Atmospheric Environment, v.7, p.311-318.

Munn, R.E. undated. A study of regional particulate pollution in the Detroit-Windsor, Sarnia-Port Huron area, unpublished manuscript, 18 pages.

Munn, R.E. & Phillips, M.L. 1973. Environmental control of air quality, unpublished manuscript.

Munn, R.E. & Ross, C.R. 1961. Analysis of smoke observations at Ottawa, Canada. Journal Air Pollution Control Association, v.11, p.410.

Munn, R.E. & Stewart, I.M. 1967. The use of meteorological towers in urban air pollution programmes. Journal Air Pollution Control Association, v.17, p.98-101.

Munn, R.E., Thomas, D.A. & Cole, A.F.W. 1969. A study of suspended particulate and iron concentrations in Windsor, Canada. Atmospheric Environment, v.3, p.1-10.

Munn, R.E., Hirt, M.S. & Findlay, B.F. 1969. A climatological study of the urban temperature anomaly in the Lakeshore environment at Toronto. Journal Applied Meteorology, v.8, p.411-422.

Myrup, L.O. 1969. A numerical model of the urban heat island. Journal Applied Meteorology, v.8, p.908-918.

Myrup, L.O. 1970. A corrigendum. Journal Applied Meteorology, v.9, p.541.

Myrup, L.O. & Morgan, D.L. 1972. Numerical model of the urban atmosphere Vol. 1: the city-surface interface. Contribution in Atmospheric Science, No. 4, University of California-Davis, 237 pages.

National Meteorological Center, 1967. The Air Pollution Potential Forecast Programme, Weather Bureau Technical Memo. WBTM-NMC 43, National Meteorological Center, Suitland, Maryland, 8 pages.

Nakaya, U. 1954. Snow Crystals: Natural and Artificial, Harvard University Press, Cambridge, Mass.

Neiburger, M. 1955. Visibility Trend in Los Angeles, Air Pollution Foundation, Report No. 11, Los Angeles, 45 pages.

Nelson, F. & Shenfeld, L. 1965. Economics, engineering and air pollution in the design of large chimneys. Journal Air Pollution Control Association, v.15, p.355-361.

Niemeyer, L.E. 1960. Forecasting air pollution potential. Monthly Weather Review, v.88, p.88-96.

Nieuwolt, S. 1966. The urban microclimate of Singapore. Journal Tropical Geography, v.22, p.30-37.

Nkemdirim, L.C., Lunn, G.R., Rowe, R.D. 1975. Pollutant concentration and stratification in the urban heat island. Water, Air and Soil Pollution, v.4, n.1, p.99-112.

Ogden, T.L. 1969. The effect on rainfall of a large steelworks. Journal Applied Meteorology, v.8, p.585-591.

Ogden, T.L. 1971. Reply. Journal Applied Meteorology, v.10, p.168.

Oke, T.R. 1969. Towards a more rational understanding of the urban heat island. Climatological Bulletin, McGill University, n.5, p.1-20.

Oke, T.R. 1972. City size and the urban heat island. Preprints American Meteorological Society Conference on Urban Environment, Philadelphia, 31st Oct. - 2nd Nov. 1972, p.144-146.

Oke, T.R. 1974. Review of Urban Climatology 1968-1973, W.M.O. Technical Note No. 134, Geneva, 132 pages.

Oke, T.R. & East, C. 1971. The urban boundary layer in Montreal. Boundary-Layer Meteorology, v.11, p.27-52.

Oke, T.R. & Fuggle, R.F. 1972. Comparison of urban/rural counter and net radiation at night. Boundary-Layer Meteorology, v.2, p.290-308.

Oke, T.R. & Hannell, F.G. 1970. The form of the urban heat island in Hamilton, Canada. In W.M.O. Urban Climates, Technical Note No. 108, p.113-126.

Oke, T.R., Maxwell, G.B. & Yap, D. 1972. Comparison of urban/rural cooling rates at night. Preprints American Meteorological Society Conference on Urban Environment, Philadelphia, p.17-21.

Okita, T. 1960. Estimation of direction of airflow from observation of rime ice. Journal of Meteorological Society of Japan, v.38, p.207-209.

Okita, T. 1965. Some chemical and meteorological measurements of air pollution in Asahikawa. International Journal Air Water Pollution, v.9, p.323-332.

Ooi Jin Bee, 1967. Land, People and Economy in Malaya, Longmans, p.303-307.

Outcalt, S.I. 1970. A Study of Needle Ice Events at Vancouver, Canada, unpublished Ph.D. thesis, University of British Columbia.

Outcalt, S.I. 1971. A numerical surface climate simulator. Geographical Analysis, p.379-393.

Outcalt, S.I. 1972. The development and application of a simple digital surface-climate simulator. Journal Applied Meteorology, v.11, p.629-636.

Ozolins, G. & Smith, R. 1968. A Rapid Survey Technique for Estimating Community Air Pollution Emissions, USDHW, Public Health Service, Environmental Health Service, and the National Air Pollution Control Administration, Raleigh, 77 pages.

Owens, I.F. & Tapper, N.J. 1977. The influence of meteorological factors on air pollution occurrence in Christchurch. Paper presented to the Ninth New Zealand Geography Conference, Dunedin, August 22 - 26, 1977.

Perkins, R.W. & Engelmann, R.J. 1966. Trace Element and Trace Radionuclide Composition of Snow and Rain, USAEC Report BNWL-SA-650.

Peterson, J.T. 1969. The climate of cities: a survey of recent Literature. National Air Pollution Control Administration Publication No. AP-59, 48 pages.

Plater-Zyberk, J. & Wohlers, H.C. 1971. Air pollution and environment: strategies for developing countries. In Englund, H.M. & Beery, W.T. (eds.) Proceedings of the Second International Clean Air Congress, Academic Press, New York & London, p.1301-1304.

Pluss, D.H. & Strauss, W. 1972. Dustfall and concentration distribution measurements around an isolated cement works. Proceedings of the 1972 Clean Air Conference, Melbourne, Clean Air Society of Australia and New Zealand, p.162-168.

Pooler, F. Jr. 1963. Airflow over a city in terrain of moderate relief. Journal Applied Meteorology, v.2, p.446-456.

Preston-Whyte, R.A. 1970. A spatial model of the urban heat island. Journal Applied Meteorology, v.9, p.571-573.

Preston-Whyte, R.A. 1971. Local Atmospheric Circulations and the Mesoclimate of Durban, unpublished Ph.D. thesis, University of Natal, Durban, 214 pages.

Probald, F. 1972. Deviations in the heat balance; the basis of Budapest's urban climate. International Geography 1972, University of Toronto Press, p.184-186.

Pryor, R.J. 1973. The changing settlement system of West Malaysia. Journal Tropical Geography, v.37, p.53-67.

Ramage, C.S. 1971. Monsoon Meteorology, Academic Press, 296 pages.

Raman, C.R.V. & Kelkar, R.R. 1972. Urban air pollution potential over Bombay, India derived from mixing depth and mean layer wind. Preprint Conference on Urban Environment and Second Conference on Biometeorology, American Meteorological Society, Philadelphia, Oct. 31 - Nov. 2, 1972, p.303-307.

Randerson, D. 1968. A Numerical Model for Predicting the Transport of Sulphur Dioxide through the Atmosphere, Ph.D. thesis, Texas A & M University, 153 pages.

Randerson, D. 1970. A numerical experiment in predicting the transport of sulphur dioxide through the atmosphere. Atmospheric Environment, v.4, p.615-632.

Reichel, E. 1933. An example of great temperature differences between town and country stations. Preussisches Meteorologisches Institut, Veroffentlichungen, Bericht No. 402, 72 pages.

Reiquam, H. 1970a. An atmospheric transport and accumulation model for airsheds. Atmospheric Environment, v.4, p.233-247.

Reiquam, H. 1970b. Sulphur: simulated long-range transport in the atmosphere. Science, v.170, p.318-320.

Renzetti, N.A. (ed.) 1955. An Aerometric Survey of the Los Angeles Basin, August to November, 1954, Report No. 9, 193-200, Air Pollution Foundation, 1(9), July, 1, 1955, 333 pages.

Reitan, C.H. 1963. Surface dewpoint and water vapour aloft. Journal Applied Meteorology, v.2, p.776-779.

Report on Rivers in the Federated Malay States, 1928, Kuala Lumpur.

Roberts, J.J., Croke, E.S. & Kennedy, A.S. 1970. An urban Atmospheric dispersion model. In Stern, A.C. (ed.) Proceedings of Symposium on Multiple-source Urban Diffusion Model, U.S. Environmental Protection Agency, p.6-1 - 6-72.

Rouse, W.R. & McCutcheon, J.G. 1970. The effect of the regional wind on air pollution in Hamilton, Ontario. Canadian Geographer, v.14, n.4, p.271-285.

Rouse, W.R. & McCutcheon, J. 1972. The diurnal behaviour of incoming solar radiation and infrared radiation in Hamilton, Canada. International Geography 1972, University of Toronto Press, p.191-196.

Rouse, W.R., Noad, D. & McCutcheon, J. 1973. Radiation, temperature and atmospheric emissivities in a polluted urban atmosphere at Hamilton, Ontario. Journal Applied Meteorology, v.12, p.798-807.

Ryan, A.P. 1977. Air pollution meteorology of Christchurch. Mauri Ora, n.1, p.3-9.

Sadeh, W.Z., Cermak, J.E. & Kawatani, T. 1971. Flow over high roughness elements. Boundary-Layer Meteorology, v.1, p.321-344.

Sanderson, M. 1974. A preliminary radiation climatology of Windsor, Ontario. Climatological Bulletin, McGill University, v.16, p.1-12.

Sasakura, K. 1965. On the distribution of relative humidity in Tokyo and its secular changes in the heart of Tokyo. Tokyo Journal of Climatology, v.2, p.45.

Schmidt, W. 1929. Distribution of minimum temperature during the frost night of May 12, 1927 within Vienna. Fortschritte der landwirtschaft, 2-21, p.681-686 (in German).

Schmidt, F.H. 1963. Local circulation around an industrial area. International Journal Air Water Pollution, v.7, p.925-926.

Schmidt, F.H. & De Boer, J.H. 1963. Local circulation around an industrial area. Berichte des Deutschen Wetterdienstes, v.91, p.28.

Schwartz, P.L. 1975. Air pollution by suspended particulate matter in Dunedin and Milton. New Zealand Journal of Science, v.18, p.337-344.

Sekiguti, T. 1964. City climate in and around the small city of Ina in Central Japan. Tokyo Geography Papers, v.8, p.93-104.

Sekiguti, T. 1970. Thermal situations of urban areas, horizontally and vertically. Urban Climates, W.M.O. Technical Note No. 108, Geneva, p.137-140.

Sekiguti, T., Shinha, T., Muto, S., Tamiya, H., Kobayashi, M. & Kawakami, K. 1972. Local temperature observations for a basin and city climate complex. Tokyo Geography Papers, v.16, p.79-93.

Sekihara, K. 1973. Some aspects of radiation climate of Tokyo as observed by the eleven year measurement of spectral global radiation from 1961-71. Meteorological Society of Japan Tokyo Journal, v.51, n.2, p.119-132.

Sham, S. 1973a. The 1967 flood in Kelantan, West Malaysia. Akademika, n.3, p.1-14.

Sham, S. 1973b. Variation of bright sunshine at Subang International Airport, 1966-72. Sains Malaysiana, v.2, n.2, p.91-103.

Sham, S. 1973c. The urban heat island: its concept and application to Kuala Lumpur. Sains Malaysiana, v.2, n.1, p.53-64.

Sham, S. 1973d. Observations on the effect of a city's form and functions on temperature patterns: a case of Kuala Lumpur. Journal Tropical Geography, v.36, p.60-65.

Sharon, D. 1974. The spatial pattern of convective rainfall in Sukumaland, Tanzania - a statistical analysis. Archiv fur Meteorologie Geophysik and Bioklimatologie, Series B, p.201-218.

Shaw, R.W. & Munn, R.E. 1971. Air pollution meteorology. In McCormac (ed.) Introduction to the Scientific Study of Atmospheric Pollution, D. Reidel Publishing Co., Dordrecht-Holland, p.53-96.

Shellard, H.C. 1959. The frequency of fog in the London area compared with that in rural area of East Anglia and Southeast England. Meteorological Magazine, v.88, p.321-323.

Shenfeld, L. 1970a. Note on Ontario's air pollution index and alert system. Journal Air Pollution Control Association, v.20, p.612.

Shenfeld, L. 1970b. Meteorological aspects of air pollution control. Atmosphere, v.8, p.3-13.

Shitara, H. 1959. The minute diurnal fluctuation of air temperature and its vertical profile in a built-up area. Geographical Review Japan, v.32, p.313-319.

Smith, L.P. 1961. Frequencies of poor afternoon visibilities in England and Wales. Meteorological Magazine, v.90, p.355-359.

Sokolovskii, M.S., Gabinova, Zh.L., Popov, B.V. & Kachor, L.F. 1966. Sanitary protection of Moscow atmospheric air. In Survey of U.S.S.R. Literature on Air Pollution and Related Occupational Diseases, translation by Levine, B.S., v.14, U.S. Department of Commerce, Washington, D.C.

Sparrow, C.J. 1969. A Geographical Review of Air Pollution in Auckland, unpublished Ph.D. thesis, University of Auckland, 228 pages.

Staff, the Malaysian Business, 1975. The Malaysian Business Interview: Encik Abdul Aziz Ahmad, Director-General of the Factory and Machinery Department. Malaysian Business, May issue, p.16-30.

Stagg, J.M. 1950. Solar radiation at Kew Observatory. Geophysical Memograph, v.11, n.86, London Meteorological Office.

Stern, A.C. (ed.) 1968. Air Pollution volume 2: Analysis, Monitoring and Surveying, Academic Press, 684 pages.

Stewart, I.M. & Matheson, D.H. 1968. Methods of relating high volume sampler particulate loadings to wind direction. Atmospheric Environment, v.2, p.181-185.

Sukanto, M. 1969. Climate of Indonesia. In Arakawa, H. (ed.) Climates of Northern and Eastern Asia, Elsevier Publishing Co., Amsterdam-London-New York, p.215-230.

Summers, P.W. 1964. An urban heat island model, its role in air pollution problems, with application to Montreal. Paper presented at the First Canadian Conference on Micro-meteorology, Toronto, Canada, 22 pages.

Summers, P.W. 1966. The seasonal, weekly, and daily cycles of atmospheric smoke content in Central Montreal. Journal Air Pollution Control Association, v.16, p.432-438.

Sundborg, A. 1950. Local climatological studies of the temperature conditions in an urban area. Tellus, v.2, p.222-232.

Tapper, N. 1976. An Investigation of Incoming Short and Long Wave Radiation over Christchurch, M.A. thesis, Canterbury University, New Zealand, 123 pages.

Terjung, W.H. 1969. The energy balance climatology of a city-man system. Annals Association of American Geographers, v.60, p.466-492.

Terjung, W.H. 1971. The effect of a cyclonic storm on the energy fluxes at the urban interface - a preliminary experiment. Archiv fur Meteorologie Geophysik and Bioklimatologie, Series B, v.19, p.367-416.

Thomas, M.K. 1971. A survey of the urban effect on the climates of Canadian cities, Canadian Atmospheric Environment Service, CDS No. 11-71, 28 pages.

Thornthwaite, C.W. 1933. The climate of the earth. Geographical Review, v.23, p.433-440.

Trewartha, G.T. 1968. An Introduction to Climate, 4th. edition, McGraw-Hill Co., 408 pages.

Turner, D.B. 1961. Relationships between 24-hour mean air quality measurements and meteorological factors in Nashville, Tennessee. Journal Air Pollution Control Association, v.11, p.483-489.

Tyson, P.D. 1963. Some climatic factors affecting atmospheric pollution in South Africa. South African Geographical Journal, v.52, p.44-54.

Tyson, P.D., du Toit, W.J.F. & Fuggle, R.F. 1972. Temperature structure above cities: review and preliminary findings from the Johannesburg urban heat island project. Atmospheric Environment, v.6, p.533-542.

Tyson, P.D., Garstang, M. & Emmitt, G.D. 1973. The Structure of Heat Island, Occasional Paper No. 12, Department of Geography, University of Witwatersrand, 71 pages.

Unit Perancang Jalan, 1973. Keputusan Kajian Lalulintas di Jalan Raya Persekutuan dan Negeri Semenanjong Malaysia 1972, Kementerian Kerjaraya & Pengangkutan, Kuala Lumpur.

Unit Perancang Jalan, 1974. Keputusan Kajian Lalulintas di Jalan Raya Persekutuan dan Negeri Semenanjong Malaysia 1973, Kementerian Kerjaraya & Pengangkutan, Kuala Lumpur.

U.S. Department of Health, Education & Welfare, 1966. The Sources of Air Pollution and Their Control, Public Health Service Publication No. 1548, Washington, D.C.

U.S. Department of Health, Education & Welfare, 1971. Sources of air pollution. In Detwyler, T.R. (ed.) Man's Impact on Environment, McGraw-Hill, p.91-97.

U.S. Environmental Protection Agency, 1971. Guide for Air Pollution Episode Avoidance, EP-76, Washington, D.C.

U.S. Environmental Protection Agency, 1972. Compilation of Air Pollutant Emission Factors, National Technical Information Service, U.S. Department of Commerce, Springfield Va. 22151.

Utusan Melayu, October 27, 1974.

Van Tassel, A.J. (ed.) 1973. Our Environment: the Outlook for 1980, Lexington Books, U.S.A., p.311-389.

Veryard, R.G. 1958. Some climatological aspects of air pollution. Smokeless Air, v.28, p.277-284.

Voorhes, A.M. & Associates and Ryckman, Edgerly, Tomlinson & Associates, 1971. A Guide for Reducing Air Pollution through Urban Planning, U.S. Department of Commerce.

Wagner, N.D. & Yu, T. 1972. Heat island formation: a numerical experiment. Preprints American Meteorological Society Conference on Urban Environment, Philadelphia, 31st Oct. - 2nd Nov., 1972, p.83-88.

Wainwright, C.W.K. & Wilson, M.J.G. 1962. Atmospheric pollution in a London Park. International Journal Air Water Pollution, v.6, p.337-347.

Walther, E.G. 1972. A rating of the major air pollutants and their sources by effect. Journal Air Pollution Control Association, v.22, p.352-355.

Walton, W.H. 1970. The measurement of respirable dust - the basic for gravimetric standards. In Proceedings of the Symposium on Respirable Coal Mine Dust, Washington, D.C., Nov. 3-4, 1969, p.5-26.

Walton, W.H. 1971. Dust sampling and dust measurement. Paper presented to the Fourth International Conference on Pneumoconiosis, International Labour Office, Bucharest, 12 pages.

Watts, I.E.M. 1949. The Equatorial Convergence Lines of the Malayan East Indies Region, Memoirs of the Malayan Meteorological Service, No. 3.

Watts, I.E.M. 1955. Equatorial Weather with particular Reference to Southeast Asia, Pitman, 224 pages.

Wiggett, P.J. 1964. The year-to-year variation of the frequency of fog at London (Heathrow) airport. Meteorological Magazine, v.93, p.305.

World Meteorological Organization, 1970. Urban Climates, Technical Note No. 108, Geneva, 390 pages.

Woollum, C.A. & Canfield, N.L. 1968. Washington Metropolitan Area Precipitation and Temperature Patterns, ESSA Technical Memo WBTM-ER-28, Garden City, New York, 32 pages.

Wuerch, D.E. 1972. An investigation of the resultant transport wind within the urban complex. Journal Applied Meteorology, v.11, p.1346-1350.

Yamamoto, G. & Shimanuki, A. 1964. Profiles of wind and temperature in the lowest 250-m in Tokyo. Geophysics, Tohoku University Science Report, Series 5, n.15, p.111-114.

Yamashita, S. 1970. An urban climatological study of the attenuation of solar radiation by air pollution in Tokyo. Geographical Review Japan, v.43, p.285-296.

Yamashita, S. 1973. Air pollution study from measurements of solar radiation. Archiv fur Meteorologie Geophysik and Bioklimatologie, Series B 21, p.243-253.

Yap, D., Gunn, K.L. & East, C. 1969. Vertical temperature distribution over Montreal. Naturalists Canada, v.96, p.561-580.

Appendix A

Method of Calculating Mixing Depth

Mixing depths in the present study are not measured directly but are estimated from routine meteorological observations following closely the procedures due to Holzworth (1969). Limitations of the procedures have been fully discussed elsewhere (Holsworth, 1964).

Upper-air soundings in the Kuala Lumpur - Petaling Jaya area are made twice daily, 0730 and 1930 hours (L.S.T.), at the Malaysian Meteorological Service Headquarters in Petaling Jaya. Data are now available from 1972 (for the morning) and 1973 (for the afternoon).

Neglecting temperature advection, afternoon mixing depths were calculated from temperatures aloft observed at 1930 hours (L.S.T.) and maximum surface temperatures observed during 1200-1600 hours (L.S.T.). A value for the morning urban mixing depth was calculated by adding 4.0°F (2.2°C) to the minimum Petaling Jaya surface temperature observed during 0200-0700 hours (L.S.T.) and assuming a dry-adiabatic lapse rate to the intersection of the observed 0730 temperature sounding. The '+4.0°F' (+2.2°C) is based on the average results obtained by Sham (1973) to allow for downtown-suburban differences of morning surface temperature.

The average wind speed through the mixing depth was calculated as a simple arithmetic average of wind speeds aloft and at the surface. Calculations of morning values were based on speeds at 0730 hours (L.S.T.) while those for the afternoon were based on speeds at 1930 hours (L.S.T.).

Values for mixing depth and average wind speed with which precipitation occurred were excluded since the dry-adiabatic assumption (no condensation) might not be applicable.

Appendix B

Respirable Dust Particulates and Meteorological Factors Likely to Affect Them

Respirable dust particulates (as recorded at the flat rooftop of the Central Electricity Board) in the Kuala Lumpur central city and selected climatic parameters (as recorded at Subang Airport) for which possible dust particulates and climate relationships have been examined are presented in the following table. The columns are arranged as follows:-

(a) Respirable dust particulates ($\mu g/m^3$) during 0730-1630 hours (L.T.)

(b) Daily average wind speed (ms^{-1})

(c) Average wind speed during period of observation (ms^{-1})

(d) Morning mixing depth (m)

(e) Afternoon mixing depth (m)

(f) Rainfall amount on preceding day (mm)

(g) Daily rainfall amount (mm)

Date	a	b	c	d	e	f	g
11. 7.75	80	0.4	1.0	500	1046	00.0	00.0
12. 7.75	50	0.8	2.5	417	0386	00.0	00.0
13. 7.75	30	1.1	1.6	326	0417	00.0	02.8
14. 7.75	90	1.1	2.2	356	0599	02.8	00.0
15. 7.75	90	1.3	2.9	273	0477	00.0	00.0
16. 7.75	60	1.0	2.1	477	0674	00.0	03.3
17. 7.75	50	1.0	1.5	424	0515	03.3	00.0
18. 7.75	70	1.2	2.9	356	0341	00.0	23.6
19. 7.75	60	1.0	2.0	333	0424	23.6	07.6
20. 7.75	40	0.6	1.4	409	0644	07.6	07.9
21. 7.75	70	0.3	0.6	508	0712	07.9	00.8
22. 7.75	60	0.3	0.5	462	1099	00.8	02.0
23. 7.75	80	0.5	1.0	576	1432	02.0	00.0
24. 7.75	70	0.5	1.1	462	0826	00.0	40.6
25. 7.75	70	0.6	1.5	432	0432	40.6	20.6
26. 7.75	60	0.7	1.0	508	0977	20.6	03.5
27. 7.75	40	0.3	0.3	326	0455	03.5	02.3
28. 7.75	70	0.4	1.0	280	0894	02.3	00.0
29. 7.75	90	0.5	1.1	515	0439	00.0	00.0
30. 7.75	80	0.7	1.7	402	1129	00.0	00.0
31. 7.75	80	0.7	1.7	364	0871	00.0	00.0
1. 8.75	90	1.0	2.3	235	1433	00.0	00.0
2. 8.75	90	1.3	3.1	417	1004	00.0	00.0
3. 8.75	40	0.9	2.2	727	1015	00.0	00.0
4. 8.75	100	1.4	3.2	515	0515	00.0	00.0
5. 8.75	90	0.7	1.5	523	0477	00.0	00.0

Date	a	b	c	d	e	f	g
6. 8.75	70	0.6	1.5	349	0326	00.0	00.0
7. 8.75	80	1.4	3.0	349	0492	00.0	00.0
8. 8.75	60	0.7	1.8	485	0333	00.0	29.2
9. 8.75	50	1.9	3.3	341	3030	29.2	01.0
10. 8.75	40	1.4	3.6	394	0576	01.0	00.0
11. 8.75	80	1.4	3.4	553	1151	00.0	00.0
12. 8.75	80	1.5	3.6	364	0758	00.0	00.0
13. 8.75	110	1.2	2.8	341	0697	00.0	00.0
14. 8.75	90	1.5	3.6	371	0659	00.0	00.0
15. 8.75	90	2.3	4.4	318	0606	00.0	00.0
16. 8.75	60	2.1	4.9	447	0674	00.0	00.0
17. 8.75	40	2.1	3.8	439	0742	00.0	00.0
18. 8.75	60	0.9	2.0	492	0296	00.0	15.5
19. 8.75	80	1.3	2.9	333	0492	15.5	00.3
20. 8.75	60	0.8	1.9	333	0333	00.3	15.2
21. 8.75	80	0.9	2.2	394	0652	15.2	00.0
22. 8.75	70	0.9	2.2	371	1296	00.0	00.0
23. 8.75	60	0.1	0.3	311	0818	00.0	00.0
24. 8.75	50	1.0	2.1	303	0697	00.0	00.0
25. 8.75	110	1.0	2.5	349	1341	00.0	00.0
26. 8.75	130	1.2	2.0	379	0576	00.0	02.0
27. 8.75	80	1.6	3.6	492	0712	02.0	09.7
28. 8.75	70	1.6	2.6	371	0962	09.7	01.0
29. 8.75	100	1.2	1.9	341	1242	01.0	00.0
30. 8.75	70	0.9	2.2	439	0409	00.0	06.1
31. 8.75	90	1.3	2.6	341	0371	06.1	15.0

Date	a	b	c	d	e	f	g
3. 9.75	80	0.3	0.5	386	0500	24.9	01.8
4. 9.75	80	1.2	2.8	379	0750	01.8	00.8
5. 9.75	90	1.0	1.3	356	0682	00.8	00.5
6. 9.75	70	0.9	2.2	508	0417	00.5	05.8
7. 9.75	60	0.6	1.2	523	0644	05.8	03.8
8. 9.75	90	0.9	2.1	424	1265	03.8	00.0
22.10.75	110	0.5	1.2	356	1090	00.0	00.0
23.10.75	80	1.0	2.5	356	0826	00.0	00.0
24.10.75	90	0.5	0.1	417	0727	00.0	00.0
27.10.75	100	0.2	0.5	356	0402	60.2	16.5
28.10.75	120	0.8	1.7	341	0477	16.5	00.3
29.10.75	100	1.6	3.7	394	0477	00.3	01.5
30.10.75	70	1.7	3.7	387	0758	01.5	13.7
31.10.75	130	1.1	2.3	402	0508	13.7	07.9
1.11.75	110	1.4	3.1	356	0152	07.9	65.0
5.11.75	90	0.3	0.7	432	0379	00.3	00.8
6.11.75	100	0.6	1.5	379	0394	00.8	00.0
7.11.75	90	0.6	1.4	364	0432	00.0	05.3
10.11.75	100	0.9	2.2	333	0606	27.2	00.8
11.11.75	120	0.8	1.8	462	0523	00.8	00.0
12.11.75	90	0.6	1.4	083	1008	00.0	00.0
13.11.75	140	1.1	1.7	515	0417	00.0	00.0
14.11.75	100	1.0	2.5	371	0492	00.0	01.0
17.11.75	80	0.2	0.5	303	0417	00.0	16.8
19.11.75	70	0.5	0.9	432	0432	20.6	23.6

Date	a	b	c	d	e	f	g
20.11.75	60	0.2	0.5	273	0500	23.6	04.3
21.11.75	70	0.4	0.9	455	0394	04.3	26.2
24.11.75	80	0.2	0.2	439	0356	21.6	01.8
26.11.75	90	0.1	0.3	273	0432	00.8	04.8
27.11.75	70	0.0	0.0	356	0568	04.8	02.3
1.12.75	70	1.1	2.6	561	0485	00.0	00.0
2.12.75	70	1.1	2.6	485	0682	00.0	00.0
3.12.75	90	1.2	2.9	356	0796	00.0	00.0
4.12.75	70	0.9	2.1	455	0333	00.0	18.0
5.12.75	80	0.6	1.2	364	0439	18.0	33.8
8.12.75	80	0.9	2.1	402	0349	13.2	00.8
9.12.75	90	0.6	1.5	462	0530	00.8	01.3
10.12.75	80	0.6	1.3	402	0773	01.3	01.5
11.12.75	70	0.5	1.3	273	0129	01.5	02.0
15.12.75	40	0.0	0.0	273	0356	02.0	03.0
16.12.75	70	0.1	0.1	432	0394	03.0	00.0
17.12.75	50	0.6	0.3	470	0659	00.0	00.0
18.12.75	80	0.9	1.4	462	0644	00.0	00.0
19.12.75	80	0.9	2.2	333	0553	00.0	00.0
22.12.75	50	0.5	1.1	311	0568	00.0	03.3
23.12.75	80	0.3	0.8	326	0402	03.3	00.0
6. 1.76	70	1.6	1.6	447	0333	00.0	74.4
7. 1.76	80	0.7	1.7	341	0311	74.4	19.1
8. 1.76	70	0.6	1.2	349	1424	19.1	00.0
9. 1.76	50	0.4	0.8	235	0955	00.0	00.0

Date	a	b	c	d	e	f	g
10. 1.76	60	1.1	2.6	333	0773	00.0	00.0
12. 1.76	80	0.8	1.8	561	0402	00.3	06.9
13. 1.76	120	0.7	1.5	349	0447	06.9	20.6
14. 1.76	60	1.0	2.1	333	0826	20.6	03.5
15. 1.76	80	0.7	1.5	379	0576	03.5	00.0
17. 1.76	100	0.9	2.2	341	0924	03.0	00.0
19. 1.76	70	0.9	1.8	470	0470	00.0	08.1
20. 1.76	50	1.0	2.2	371	0871	08.1	00.0
21. 1.76	90	0.7	1.6	386	1091	00.0	00.5
22. 1.76	80	1.0	2.3	333	0265	00.5	04.3
23. 1.76	70	1.1	2.7	462	0644	04.3	00.0
26. 1.76	100	1.1	2.5	364	1402	00.0	00.0
27. 1.76	100	1.4	3.4	455	0796	00.0	00.0
28. 1.76	90	1.2	2.8	152	1106	00.0	00.0
29. 1.76	100	1.1	2.5	568	0788	00.0	00.0
30. 1.76	70	1.0	2.4	303	1477	00.0	00.0
4. 2.76	100	0.8	1.8	417	0405	05.5	00.4
5. 2.76	90	1.5	2.8	394	0796	00.4	16.0
6. 2.76	90	1.2	2.7	455	1053	16.0	00.0
9. 2.76	50	1.4	3.4	477	0341	00.0	00.3
10. 2.76	60	1.3	3.1	333	0326	00.3	00.0
11. 2.76	70	1.4	3.0	333	1167	00.0	00.0
12. 2.76	70	1.4	3.4	341	0985	00.0	00.0
13. 2.76	100	1.2	2.9	515	1273	00.0	00.0
14. 2.76	90	1.2	2.9	341	0318	00.0	14.9
16. 2.76	70	0.7	1.7	341	1055	00.0	00.0
17. 2.76	70	1.1	2.4	455	0462	00.0	38.0

Date	a	b	c	d	e	f	g
18. 2.76	110	1.2	2.8	258	033	38.0	01.3
19. 2.76	70	1.0	2.4	439	0712	01.3	00.0
20. 2.76	90	1.3	3.0	432	0849	00.0	00.0
21. 2.76	60	1.3	3.2	455	0788	00.0	00.0
23. 2.76	70	1.4	3.0	379	0386	00.0	02.4
24. 2.76	60	1.6	3.4	447	0455	02.4	01.0
25. 2.76	80	1.4	3.0	379	0591	01.0	00.4
26. 2.76	90	1.5	3.5	349	0477	00.4	04.2
27. 2.76	70	1.1	2.3	333	0508	04.2	26.9
1. 3.76	60	1.4	2.7	318	0568	02.6	03.5
2. 3.76	100	1.3	3.1	447	0917	03.5	00.0
3. 3.76	80	1.2	2.9	356	3644	00.0	00.0
4. 3.76	60	1.3	2.4	455	0515	00.0	00.0
5. 3.76	80	1.3	2.7	356	1280	00.0	11.7
6. 3.76	70	1.0	2.4	455	0750	11.7	00.0
8. 3.76	70	1.4	3.2	462	0765	00.0	00.0
9. 3.76	70	1.3	2.9	417	0803	00.0	06.1
10. 3.76	60	2.5	4.9	379	0902	06.1	00.0
11. 3.76	70	1.6	3.7	409	0311	00.0	46.2
12. 3.76	60	0.9	2.0	356	0492	46.2	09.1
15. 3.76	70	1.2	2.6	242	0424	07.4	00.8
16. 3.76	80	1.0	2.2	318	0629	00.8	05.0
17. 3.76	70	1.1	2.7	417	0462	05.0	00.0
18. 3.76	80	1.4	3.2	439	0318	00.0	09.1
19. 3.76	90	1.0	2.3	318	0424	09.1	00.0
20. 3.76	80	1.1	2.4	538	0591	00.0	04.6

Date	a	b	c	d	e	f	g
22. 3.76	80	1.4	2.8	455	0379	39.1	04.8
23. 3.76	60	1.0	1.4	341	0947	04.8	02.5
25. 3.76	60	1.3	2.2	265	0530	71.6	44.5
26. 3.76	80	1.1	2.1	341	0341	44.5	00.0
27. 3.76	70	1.0	2.0	341	0386	00.0	00.0
29. 3.76	70	1.1	2.3	333	0356	08.4	34.0
30. 3.76	80	1.6	3.3	341	0424	34.0	00.0
31. 3.76	70	1.1	2.4	386	0470	00.0	25.4
1. 4.76	60	1.5	2.3	280	0682	25.4	00.0
2. 4.76	70	1.0	2.3	356	0356	00.0	19.5
3. 4.76	70	1.3	1.5	439	0682	19.5	00.0
5. 4.76	80	0.9	2.1	432	0258	23.6	08.6
6. 4.76	100	0.5	0.9	379	0394	08.6	36.6
7. 4.76	70	1.1	2.7	424	0530	36.6	01.3
8. 4.76	130	0.9	2.1	326	0379	01.3	05.3
9. 4.76	80	1.2	2.8	341	0318	05.3	17.0
10. 4.76	90	0.5	0.9	379	0349	17.0	21.1
11. 4.76	70	1.0	2.2	311	0417	21.1	00.0
12. 4.76	90	0.9	1.8	371	0364	00.0	18.8
13. 4.76	60	1.0	1.9	386	0432	18.8	27.7
14. 4.76	80	1.8	3.3	326	1015	27.7	01.8
15. 4.76	90	1.6	3.0	530	0765	01.8	00.0
16. 4.76	80	0.8	1.1	477	0439	00.0	00.3
17. 4.76	80	0.9	2.1	424	0492	00.3	00.0
18. 4.76	70	0.6	1.3	379	0705	00.0	01.8
19. 4.76	90	1.1	2.6	318	0432	01.8	01.0

Date	a	b	c	d	e	f	g
20. 4.76	100	0.7	1.7	439	0492	01.0	01.0
21. 4.76	70	0.8	1.0	379	0576	01.0	78.5
22. 4.76	80	0.7	1.6	326	0311	78.5	06.6
23. 4.76	50	4.0	0.9	402	0788	06.6	05.8
24. 4.76	70	0.6	1.1	394	0144	05.8	32.8
25. 4.76	70	0.3	0.8	409	0455	32.8	23.6
26. 4.76	90	1.0	2.2	432	0515	23.6	00.5
27. 4.76	70	0.3	0.7	432	0424	00.5	00.8
28. 4.76	90	0.3	0.7	432	0576	00.8	00.0
29. 4.76	80	1.0	2.1	364	0689	00.0	04.3
30. 4.76	80	1.3	2.2	333	0561	04.3	00.0
1. 5.76	90	1.3	2.8	356	0553	00.0	00.0
2. 5.76	100	1.0	1.8	462	0606	00.0	00.0
3. 5.76	90	1.2	1.0	409	0515	00.0	00.8
4. 5.76	100	0.7	0.8	417	0614	00.8	03.3
5. 5.76	90	0.6	1.3	409	0871	03.3	22.5
6. 5.76	80	0.8	1.7	318	0826	22.5	00.0
7. 5.76	80	0.3	0.7	455	0417	00.0	00.0
8. 5.76	90	1.0	2.3	280	0629	00.0	00.0
9. 5.76	80	0.7	1.7	402	0758	00.0	00.0
10. 5.76	90	0.6	1.3	371	0349	00.0	00.1
11. 5.76	60	0.2	0.4	432	0394	00.1	04.5
12. 5.76	80	0.8	1.9	326	0644	04.5	00.0
13. 5.76	80	0.4	0.8	356	0409	00.0	04.9
14. 5.76	100	0.9	2.1	303	0485	04.9	00.0
15. 5.76	60	1.0	2.4	273	0515	00.0	00.0

Date	a	b	c	d	e	f	g
16. 5.76	90	1.2	2.8	455	0621	00.0	00.0
17. 5.76	70	1.0	2.3	326	0599	00.0	00.0
18. 5.76	90	1.0	2.5	386	0758	00.0	00.0
19. 5.76	90	0.5	1.1	311	0546	00.0	00.0
20. 5.76	80	0.4	0.9	371	0606	00.0	00.3
21. 5.76	70	0.4	0.8	455	0962	00.3	28.6
22. 5.76	70	0.4	0.9	326	1394	28.6	00.0
23. 5.76	80	0.6	1.4	576	1356	00.0	00.0
24. 5.76	50	0.8	2.0	500	1394	00.0	00.0
25. 5.76	50	0.6	1.4	371	0750	00.0	00.0
26. 5.76	70	0.4	0.9	326	0750	00.0	00.0
27. 5.76	80	0.6	1.5	265	0985	00.0	00.0
28. 5.76	80	0.9	2.1	477	0879	00.0	00.0
29. 5.76	90	1.3	2.9	394	0515	00.0	00.0
30. 5.76	60	1.1	2.6	386	0424	00.0	01.7
31. 5.76	80	1.2	2.7	235	0470	01.7	00.7
1. 6.76	70	0.6	1.1	424	0833	00.7	01.3
2. 6.76	60	1.4	1.9	364	0303	01.3	01.8
3. 6.76	80	1.7	3.3	417	0667	01.8	03.5
4. 6.76	60	1.4	3.0	333	0682	03.5	00.0
5. 6.76	60	1.0	2.3	371	0356	00.0	12.2
6. 6.76	70	1.0	2.3	333	0273	12.2	15.7
7. 6.76	90	0.8	1.7	349	0296	15.7	01.3
8. 6.76	70	0.8	1.9	371	0553	01.3	00.0
9. 6.76	80	0.9	2.2	333	0682	00.0	00.8
12. 6.76	80	1.1	2.3	333	0856	02.3	00.8

Date	a	b	c	d	e	f	g
13. 6.76	70	1.1	2.4	341	0909	00.8	00.0
14. 6.76	70	0.7	1.5	394	0591	00.0	00.0
15. 6.76	60	1.3	2.9	326	1530	00.0	00.0
16. 6.76	80	0.9	2.0	424	0318	00.0	00.3
17. 6.76	60	0.4	1.0	311	0492	00.3	26.9
18. 6.76	80	0.7	1.5	296	0924	26.9	00.5
19. 6.76	70	0.6	1.5	341	0939	00.5	00.0
20. 6.76	80	0.6	1.4	258	1023	00.0	00.0
22. 6.76	90	1.3	3.0	394	0780	00.0	00.0
23. 6.76	90	1.2	2.5	311	0402	00.0	00.3
25. 6.76	60	0.7	1.3	379	0606	00.5	03.0
26. 6.76	60	1.1	2.4	492	0705	03.0	00.0
27. 6.76	60	1.1	1.8	417	0955	00.0	05.6
28. 6.76	60	0.7	1.7	311	1061	05.6	00.0
29. 6.76	50	1.2	2.9	417	0682	00.0	00.0
30. 6.76	60	1.1	2.6	311	0909	00.0	00.0

Appendix C

Respirable Dust Particulates for Selected Land Use Types

Besides data of respirable dust particulates taken from the flat rooftop building of the Central Electricity Board in the Kuala Lumpur central city (Appendix B), samples were also obtained for three other different land uses: industrial area (Factory site, Rothman of Pall Mall, Petaling Jaya), residential zone (Section 12/16 Petaling Jaya), and a parkland area (the Lake Garden). These are tabulated thus:

(a) Respirable dust particulates for industrial area ($\mu g/m^3$)

(b) Respirable dust particulates for residential zone ($\mu g/m^3$)

(c) Respirable dust particulates for parkland ($\mu g/m^3$)

Date	(a)	(b)	(c)
23. 8.75	140	-	-
24. 8.75	70	30	-
25. 8.75	160	40	-
26. 8.75	170	70	-
27. 8.75	120	30	-
28. 8.75	100	20	-
29. 8.75	120	30	-
30. 8.75	70	30	-
31. 8.75	50	20	-
1. 9.75	40	30	-
2. 9.75	70	30	-
3. 9.75	110	60	-
4. 9.75	60	30	20
5. 9.75	80	20	30
6. 9.75	70	30	10
7. 9.75	30	20	-
8. 9.75	100	30	-
9. 9.75	120	30	-
10. 9.75	90	20	20
11. 9.75	50	20	-
12. 9.75	100	30	20
13. 9.75	80	30	-
14. 9.75	90	20	30
15. 9.75	130	40	-
16. 9.75	130	40	-
17. 9.75	100	30	-
18. 9.75	140	50	30

Date	(a)	(b)	(c)
19. 9.75	110	50	-
20. 9.75	80	40	30
21. 9.75	70	20	-
22. 9.75	-	30	10
23. 9.75	-	-	10
24. 9.75	-	-	-
25. 9.75	-	-	20
26. 9.75	-	-	20
27. 9.75	-	-	-
28. 9.75	-	-	40
29. 9.75	-	-	20
30. 9.75	-	-	20

Appendix D

Vertical Distribution of Respirable Dust Particulates in the Urbanized Area of Kuala Lumpur

Samples of respirable dust particulates from different heights in the Kuala Lumpur central city were collected twice daily: 0730-1630 hours (L.T.) and 1630-0130 hours (L.T.). The levels for which respirable dust particulates were obtained are as follows:-

(1) 4-foot (1.22-m) level

(2) 30-foot (9.14-m) level

(3) 165-foot (50.29-m) level

The first two were within the compound of the Central Electricity Board building, while the third one was on the roof of 'Wisma Yakin' building. Data of respirable dust particulates obtained from these different levels are listed under the appropriate headings with (a) denoting data collected during 0730-1630 hours (L.T.) and (b) denoting those collected during 1630-0130 hours (L.T.). For the 30-foot (9.14-m) level, only values collected during 1630-0130 hours (L.T.) are presented; those collected during 0730-1630 hours (L.T.) have been given earlier in Appendix B. Values of respirable dust particulates are in $\mu g/m^3$.

Date	4-foot(1.22-m)		30-foot(9.14-m)		165-foot(50.29-m)	
	(a)	(b)	(a)	(b)	(a)	(b)
11. 7.75	-	-	-	50	-	-
12. 7.75	-	-	-	30	-	-
13. 7.75	-	-	-	20	-	-
14. 7.75	-	-	-	70	-	-
15. 7.75	-	-	-	40	-	-
16. 7.75	-	-	-	30	-	-
17. 7.75	-	-	-	30	-	-
18. 7.75	-	-	-	40	-	-
19. 7.75	-	-	-	30	50	30
20. 7.75	-	-	-	20	30	10
21. 7.75	-	-	-	30	40	20
22. 7.75	-	-	-	30	40	20
23. 7.75	-	-	-	40	50	30
24. 7.75	-	-	-	30	30	10
25. 7.75	-	-	-	30	30	10
26. 7.75	-	-	-	30	30	20
27. 7.75	-	-	-	20	30	10
28. 7.75	-	-	-	40	50	20
29. 7.75	-	-	-	30	40	20
30. 7.75	-	-	-	30	40	20
31. 7.75	-	-	-	50	30	10
1. 8.75	-	-	-	40	50	30
2. 8.75	-	-	-	30	30	20
3. 8.75	-	-	-	20	20	10
4. 8.75	-	-	-	60	70	30
5. 8.75	-	-	-	40	50	30

Date	4-foot(1.22-m)		30-foot(9.14-m)		165-foot(50.29-m)	
	(a)	(b)	(a)	(b)	(a)	(b)
6. 8.75	-	-	-	30	50	20
7. 8.75	-	-	-	50	30	20
8. 8.75	-	-	-	20	30	10
9. 8.75	-	-	-	20	20	10
10. 8.75	-	-	-	20	30	20
11. 8.75	-	-	-	40	30	20
12. 8.75	-	-	-	30	40	30
13. 8.75	-	-	-	60	60	40
14. 8.75	-	-	-	40	50	30
15. 8.75	-	-	-	50	50	40
16. 8.75	-	-	-	30	40	20
17. 8.75	-	-	-	30	30	10
18. 8.75	-	-	-	30	30	10
19. 8.75	-	-	-	30	40	20
20. 8.75	-	-	-	20	30	10
21. 8.75	-	-	-	50	-	-
22. 8.75	-	-	-	40	-	-
23. 8.75	60	40	-	-	-	-
24. 8.75	50	40	-	-	-	-
25. 8.75	110	90	-	-	-	-
26. 8.75	130	70	-	-	-	-
27. 8.75	80	60	-	-	-	-
28. 8.75	70	50	-	-	-	-
29. 8.75	100	70	-	-	-	-
30. 8.75	70	40	-	-	-	-
31. 8.75	90	60	-	-	-	-

Date	4-foot(1.22-m)		30-foot(9.14-m)		165-foot(50.29-m)	
	(a)	(b)	(a)	(b)	(a)	(b)
1. 9.75	50	30	-	-	-	-
2. 9.75	50	30	-	-	-	-
3. 9.75	80	40	-	-	-	-
4. 9.75	80	60	-	-	-	-
5. 9.75	90	50	-	-	-	-
6. 9.75	70	40	-	-	-	-
7. 9.75	60	20	-	-	-	-
8. 9.75	90	60	-	-	-	-

Appendix E

Regression Equations Used in Estimating Missing Data at Weld Reservoir

Partial or complete loss of solar radiation, sunshine duration, air temperature and relative humidity data at Weld Reservoir occurred on several occasions as a result of faulty instruments. On one occasion during December, 1975, several of the stands upon which the instruments were placed were blown down by strong winds. Over the 1975 period, the missing data for each of the parameters are as follows:-

Relative humidity (R.H.)	=	2.19%
Air temperature (T)	=	2.19%
Solar radiation (Q + q)	=	10.95%
Sunshine duration (S.D.)	=	4.10%

Data for the missing days were obtained using regression equations in the form

(1) Relative humidity (R.H.)

$$R.H.(Weld) = 0.81\ R.H.(Petaling\ Jaya) + 12.97\% \quad ....(A.1)$$

C.C. = 0.716 S.E.E. = $\pm$ 4.2952%

(2) Air temperature (T)

$$T(Weld) = 0.85T(Petaling\ Jaya) + 13.85^{o}F \quad ....(A.2)$$

C.C. = 0.610 S.E.E. = $\pm$ 2.1632^{o}F

(3) Solar radiation (Q + q)

$(Q + q)(Weld) = 1.02(Q + q)(Subang) + 122.83 \text{ mwhr/cm}^2$ ....(A.3)

C.C. = 0.796 S.E.E. = $\pm$ 87.0239 mwhr/cm^2

(4) Sunshine duration (S.D.)

S.D.(Weld) = 0.64S.D.(Subang) + 1.81 hours ....(A.4)

C.C. = 0.680 S.E.E. = $\pm$ 1.9356 hours

Appendix F

Climatic Parameters Recorded at Weld Reservoir during 1975

A climate station measuring relative humidity (R.H.), air temperature (T), solar radiation (Q + q), sunshine duration (S.D.), and precipitation (P) was set up at Weld Reservoir in the city area. Data for 1975 which are tabulated in this Appendix have been used to illustrate urban effects upon climatic parameters. The columns are arranged as follows:-

R.H. = relative humidity (percent)

T = air temperature (^{o}C)

(Q + q) = solar radiation ($mwhr/cm^2$)

S.D. = sunshine duration (hours)

P = precipitation (mm)

Estimated values using the regression equations shown in Appendix E, are indicated by asterisks.

Date	R.H.	T	(Q + q)	S.D.	P
1. 1.75	79.2	27.4	757.3	04.50	02.28
2. 1.75	80.4	27.1	476.9	05.40	01.77
3. 1.75	77.5	28.2	613.4	03.10	23.62
4. 1.75	77.5	28.0	476.9	01.85	00.00
5. 1.75	81.9	27.9	467.5	05.55	00.00
6. 1.75	78.6	29.2	656.1	06.45	01.01
7. 1.75	72.0	29.4	628.3	06.60	00.00
8. 1.75	73.8	29.4	594.7	06.80	00.00
9. 1.75	74.4	28.9	585.3	04.85	02.54
10. 1.75	79.0	27.7	574.1	04.81*	01.01
11. 1.75	82.6	27.9	489.9	03.55	01.27
12. 1.75	74.1	27.2	607.8	06.45	03.55
13. 1.75	77.3	24.7	590.9	04.80	00.00
14. 1.75	78.5	23.6	396.4	00.00	01.52
15. 1.75	76.7	24.0	733.0	07.40	00.00
16. 1.75	78.8	24.0	547.9	05.85	01.27
17. 1.75	76.9	24.2	680.7	07.25	10.66
18. 1.75	74.1	24.8	731.2	08.25	12.44
19. 1.75	68.1	24.9	593.8	10.20	00.00
20. 1.75	66.3	27.2	695.6	11.00	00.00
21. 1.75	67.5	28.5	834.0	11.05	00.00
22. 1.75	74.8	26.4	628.9	06.75	00.00
23. 1.75	69.4	28.5	693.8	06.00	08.63
24. 1.75	71.4	29.2	777.9	08.70	00.00
25. 1.75	70.1	29.7	884.5	10.40	00.00
26. 1.75	71.0	28.9	529.2	05.10	00.00
27. 1.75	70.1	29.1	579.7	09.25	00.00

Date	R.H.	T	(Q + q)	S.D.	P
28. 1.75	73.5	28.1	648.8	08.25	00.00
29. 1.75	66.7	29.4	819.1	09.55	45.21
30. 1.75	70.3	29.2	742.8	09.85	00.00
31. 1.75	70.4	29.5	600.3	06.90	11.43
1. 2.75	71.7	29.9	770.4	08.05	00.00
2. 2.75	71.0	29.9	732.3	06.54	00.00
3. 2.75	72.0	29.2	595.1	05.97	00.00
4. 2.75	77.1	28.5	501.2	05.35	00.00
5. 2.75	73.3	29.9	643.3	08.70	00.25
6. 2.75	75.3	28.9	589.1	06.70	00.00
7. 2.75	71.8	27.3	680.7	06.25	00.00
8. 2.75	78.3	28.1	486.2	02.80	00.00
9. 2.75	79.9	26.3	215.1	00.00	17.01
10. 2.75	75.9	27.1	452.5	02.40	14.98
11. 2.75	77.5	26.4	411.4	01.15	25.14
12. 2.75	76.8	26.0	484.3	04.00	29.21
13. 2.75	75.4	26.7	566.6	06.30	61.72
14. 2.75	74.8	27.3	600.3	06.15	23.62
15. 2.75	65.3	27.3	583.4	06.35	18.79
16. 2.75	73.9	26.7	605.9	05.35	04.57
17. 2.75	73.4	26.6	661.9	07.40	41.40
18. 2.75	70.8	27.0	635.0	07.00	07.11
19. 2.75	68.2	28.2	669.5	08.45	00.76
20. 2.75	68.2	29.8	882.6	10.95	00.25
21. 2.75	64.7	29.7	804.1	08.65	00.00
22. 2.75	65.3	30.1	838.7	08.50	00.00

Date	R.H.	T	(Q + q)	S.D.	P
23. 2.75	80.0	25.2	086.0	00.00	01.27
24. 2.75	74.5	28.0	748.0	09.20	07.11
25. 2.75	69.9	28.6	712.5	07.55	00.00
26. 2.75	79.2	27.4	286.1	09.25	00.76
27. 2.75	66.6	29.3	749.9	00.30	04.82
28. 2.75	68.9	29.1	628.3	02.00	00.00
1. 3.75	69.4	29.2	639.5	08.40	00.00
2. 3.75	72.5	28.7	796.1	07.75	00.00
3. 3.75	79.7	25.5	233.8	01.60	36.06
4. 3.75	78.6	25.7	398.3	01.95	23.36
5. 3.75	77.6	26.6	536.3	04.75	01.52
6. 3.75	75.9	27.1	577.8	05.70	06.60
7. 3.75	83.6	26.3	413.3	00.95	19.81
8. 3.75	73.7	27.3	594.7	05.80	04.31
9. 3.75	82.7	27.9	820.9	07.55	02.54
10. 3.75	66.8	28.5	710.6	02.50	26.41
11. 3.75	60.8	29.1	764.8	02.40	00.00
12. 3.75	67.6	28.7	729.3	00.90	00.00
13. 3.75	72.3	27.9	579.7	00.05	00.00
14. 3.75	77.1	29.3	749.9	07.50	52.57
15. 3.75	75.5	29.8	837.8	10.00	00.00
16. 3.75	75.6	28.4	620.8	05.50	00.00
17. 3.75	67.9	27.4	625.5	05.40	00.00
18. 3.75	70.3	37.9	595.7	04.85	37.33
19. 3.75	67.7	28.7	650.8	05.70	00.50
20. 3.75	67.1	29.7	841.5	08.80	00.25

Date	R.H.	T	(Q + q)	S.D.	P
21. 3.75	65.6	29.3	728.3*	04.20	00.25
22. 3.75	66.3	29.9	727.4	07.25	00.00
23. 3.75	70.8	27.7	445.1	02.30	00.00
24. 3.75	66.8	29.2	725.0	03.90	03.04
25. 3.75	65.4	29.7	862.1	06.80	00.00
26. 3.75	67.6	26.7	734.9	07.40	00.00
27. 3.75	68.4	28.9	607.8	07.50	27.94
28. 3.75	69.0	29.2	617.1	06.05	13.97
29. 3.75	70.6	28.2	512.4	06.95	00.00
30. 3.75	64.8	28.7	809.7	06.85	18.79
31. 3.75	67.2	27.6	675.2	05.75	00.00
1. 4.75	62.9	28.9	759.2	07.90	00.00
2. 4.75	68.3	28.2	605.8	05.70	00.00
3. 4.75	68.8	27.8	663.8	07.10	68.07
4. 4.75	69.9	28.1	581.5	03.90	00.00
5. 4.75	69.9	28.9	660.1	04.90	00.50
6. 4.75	68.9	28.7	585.3	03.00	00.00
7. 4.75	78.0	28.6	665.7	06.45	05.33
8. 4.75	80.0	28.2	635.8	05.45	03.81
9. 4.75	83.0	28.1	615.2	05.00	15.49
10. 4.75	77.4	29.3	719.9	07.75	05.58
11. 4.75	83.1	28.9	852.7	07.95	40.13
12. 4.75	78.3	29.5	655.1*	06.50	00.00
13. 4.75	82.1	28.7	663.8	07.60	12.19
14. 4.75	82.3	26.9	710.6	06.90	11.93
15. 4.75	82.7	27.8	534.8	03.20	00.00

Date	R.H.	T	(Q + q)	S.D.	P
16. 4.75	88.7	27.3	628.3	06.25	125.22
17. 4.75	82.8	27.9	701.2	07.20	01.01
18. 4.75	86.0	27.1	529.2	05.10	33.78
19. 4.75	85.3	27.6	476.8	05.50	66.04
20. 4.75	84.8	28.1	609.6	06.10	04.06
21. 4.75	83.4	27.6	648.8	07.25	37.84
22. 4.75	80.8	27.1	549.7	03.55	00.00
23. 4.75	83.0	27.9	650.7	05.95	14.73
24. 4.75	83.3	25.8	673.2	07.85	43.94
25. 4.75	84.3	27.1	495.5	02.90	22.09
26. 4.75	85.0	28.2	470.3	06.50	09.14
27. 4.75	75.2	29.2	553.5	08.35	00.00
28. 4.75	75.9	29.6	721.6	08.15	00.00
29. 4.75	81.4	30.0	658.2	08.05	00.00
30. 4.75	79.7	29.4	621.2	05.30	00.00
1. 5.75	86.7	27.6	577.8	04.60	09.39
2. 5.75	76.0	29.4	716.2	08.70	00.00
3. 5.75	73.4	29.7	719.9	08.75	00.00
4. 5.75	71.5	29.8	781.6	10.20	00.00
5. 5.75	70.8	30.1	807.8	09.35	00.00
6. 5.75	78.9	28.6	562.8	05.75	07.11
7. 5.75	80.2	28.6	605.5*	05.70	00.00
8. 5.75	82.5	28.5	512.3	03.25	00.00
9. 5.75	81.5	29.0	697.4	05.95	06.60
10. 5.75	80.7	29.7	544.4	03.79	00.00
11. 5.75	78.2	29.3	727.6	07.34*	00.00

Date	R.H.	T	(Q + q)	S.D.	P
12. 5.75	75.2	29.5	656.3	08.20	00.00
13. 5.75	77.3	29.1	585.3	03.30	00.00
14. 5.75	78.9	29.6	643.2	06.70	00.50
15. 5.75	79.1	28.6	604.0	04.95	00.00
16. 5.75	75.0	29.6	680.6	08.10	00.00
17. 5.75	77.0	29.7	592.7	05.95	00.00
18. 5.75	75.2	29.3	521.7	02.85	00.00
19. 5.75	76.4	27.9	682.5	07.00	03.04
20. 5.75	78.8	28.8	519.8	05.85	00.00
21. 5.75	86.8	27.3	409.5	04.55	17.52
22. 5.75	78.5	28.9	731.1	08.35	00.00
23. 5.75	75.8	29.1	675.0	07.25	00.00
24. 5.75	80.7	28.7	519.8	04.80	16.00
25. 5.75	82.5	27.7	525.4	05.20	34.29
26. 5.75	90.7	25.7	366.2*	03.37	29.21
27. 5.75	73.0	29.5	473.1	04.65	00.00
28. 5.75	75.5	28.8	723.6	08.60	00.00
29. 5.75	82.8	28.1	449.3	05.95	06.85
30. 5.75	85.2	27.6	482.3	06.75	06.85
31. 5.75	74.3	29.0	666.8	04.80	00.00
1. 6.75	77.5	28.3	695.7*	06.45	01.77
2. 6.75	76.1	28.2	686.3	06.40	00.00
3. 6.75	81.7	27.6	608.1	06.45	25.65
4. 6.75	83.5	27.5	658.2	05.65	01.52
5. 6.75	79.5	28.4	538.0	00.95	00.00
6. 6.75	73.5	29.9	699.2	09.40	00.00

Date	R.H.	T	(Q + q)	S.D.	P
7. 6.75	78.0	29.4	607.6*	02.25	00.00
8. 6.75	76.0	29.7	691.9	08.40	00.00
9. 6.75	82.5	27.7	642.9	03.45	30.48
10. 6.75	82.3	26.6	403.9	00.10	00.00
11. 6.75	75.3	25.4	668.2	08.80	00.00
12. 6.75	83.5	25.6	439.4	04.85	05.08
13. 6.75	78.2	28.5	600.2	03.15	01.52
14. 6.75	81.6	28.4	577.1	02.65	00.00
15. 6.75	85.1	27.0	516.5	03.00	00.00
16. 6.75	87.2	26.2	334.7	01.40	03.81
17. 6.75	78.8	27.6	533.1*	02.95	00.00
18. 6.75	74.4	28.6	641.4	02.85	01.01
19. 6.75	78.4	28.4	501.2	02.30	00.00
20. 6.75	76.8	28.6	617.3	01.30	00.50
21. 6.75	75.8	28.5	433.8	00.90	00.00
22. 6.75	74.3	29.4	685.6*	08.70	00.25
23. 6.75	77.8	29.3	538.6	04.25	00.00
24. 6.75	78.2	29.2	555.4	06.35	00.00
25. 6.75	72.5	29.1	630.1	05.40	00.00
26. 6.75	74.8	26.7	600.3	07.30	00.00
27. 6.75	74.4	29.2	523.6	02.70	00.00
28. 6.75	75.8	30.1	686.3	07.70	02.92
29. 6.75	77.4	29.0	486.2	06.05	06.35
30. 6.75	78.5	28.2	617.1	04.75	00.00
1. 7.75	74.4	28.4	682.5	08.75	00.00
2. 7.75	83.1	26.7	615.3	07.05	18.03

Date	R.H.	T	(Q + q)	S.D.	P
3. 7.75	85.1	26.3	572.3	05.35	06.60
4. 7.75	88.5	25.8	407.7	03.35	04.82
5. 7.75	77.6	27.8	656.4	08.00	00.00
6. 7.75	81.8	27.4	514.3	04.10	00.00
7. 7.75	86.7	27.8	394.6	02.10	02.28
8. 7.75	82.7	26.6	546.1	05.85	00.00
9. 7.75	87.5	25.6	387.1	02.75	03.30
10. 7.75	75.6	28.2	639.6	09.45	00.00
11. 7.75	81.6	26.7	319.8	00.00	00.00
12. 7.75	80.8	29.5	493.7	05.87	03.04
13. 7.75	83.9	26.2	568.5	05.75	44.95
14. 7.75	82.8	26.4	469.4	05.50	00.00
15. 7.75	82.1	27.7	639.6	05.95	00.00
16. 7.75	78.6	28.3	686.3	07.90	16.51
17. 7.75	83.8	27.1	555.4	03.75	11.17
18. 7.75	84.1	26.4	589.1	05.65	30.73
19. 7.75	87.5	26.3	563.0*	04.40	01.01
20. 7.75	83.0	25.4	536.7	06.25	37.33
21. 7.75	83.7	26.4	448.8	03.00	01.27
22. 7.75	81.1	26.7	576.0	04.95	05.84
23. 7.75	81.8	26.7	555.4	05.75	00.00
24. 7.75	80.8	27.6	514.3	06.05	01.01
25. 7.75	82.0	26.9	493.7	05.40	17.01
26. 7.75	80.1	27.0	650.8	07.25	06.60
27. 7.75	84.0	24.9	278.7	00.00	08.89
28. 7.75	76.4	26.7	646.4	04.31	00.00
29. 7.75	83.1	26.1	475.0	05.15	09.39

Date	R.H.	T	(Q + q)	S.D.	P
30. 7.75	72.3	28.2	628.4	03.00	00.00
31. 7.75	68.8	28.4	557.3	05.75	00.00
1. 8.75	68.0	28.8	460.1	09.90	00.00
2. 8.75	69.5	29.3	789.2	10.25	06.35
3. 8.75	73.3	28.1	620.9	06.60	00.00
4. 8.75	72.4	26.4	611.5	05.65	00.00
5. 8.75	78.8	25.2	499.3	04.60	00.00
6. 8.75	79.8	24.2	439.5	02.25	01.77
7. 8.75	75.0	25.4	624.6	05.70	00.00
8. 8.75	84.9	22.7	557.8	01.50	23.62
9. 8.75	73.5	26.1	754.3	07.60	01.27
10. 8.75	72.1	25.8	594.0*	03.28*	00.00
11. 8.75	70.4	26.3	648.9	07.75	00.00
12. 8.75	80.5	27.4	720.0	09.00	00.00
13. 8.75	79.6	27.9	723.7	08.70	00.00
14. 8.75	77.3	27.3	609.7	06.55	00.00
15. 8.75	72.8	27.8	693.8	07.75	00.00
16. 8.75	72.1	28.6	635.8	07.70	00.00
17. 8.75	71.5	28.4	678.9	08.20	00.00
18. 8.75	85.6	25.5	484.4	08.45	61.21
19. 8.75	79.3	26.2	741.2	04.30	10.41
20. 8.75	85.3	25.2	448.2	04.25	05.08
21. 8.75	75.2	27.3	697.8	05.50	00.76
22. 8.75	71.8	27.7	762.3*	07.45	00.00
23. 8.75	78.8	27.7	461.9	02.55	00.00
24. 8.75	71.6	27.7	867.7	08.00	00.00
25. 8.75	72.3	27.6	647.1	08.20	02.03

Date	R.H.	T	(Q + q)	S.D.	P
26. 8.75	78.3	27.3	764.9	08.40	00.00
27. 8.75	76.3	27.7	632.1	08.00	01.27
28. 8.75	74.8	28.0	716.2	05.25	02.54
29. 8.75	74.8	27.4	709.6*	06.11	00.00
30. 8.75	84.0	26.2	473.2	03.90	02.28
31. 8.75	86.5	25.2	602.7	05.46*	00.00
1. 9.75	85.6	24.6	633.8	04.69	00.00
2. 9.75	87.2	24.1	370.3	03.09*	00.00
3. 9.75	82.6	25.4	458.1	02.00	02.28
4. 9.75	77.9	27.1	729.8	07.40	22.35
5. 9.75	78.1	26.7	626.5	03.05	00.00
6. 9.75	77.9	27.3	620.1	05.10	19.05
7. 9.75	87.2	25.7	448.6	02.29	02.54
8. 9.75	73.5	26.3	693.8	08.90	00.00
9. 9.75	77.4	26.8	673.2	06.45	06.35
10. 9.75	81.7	27.0	645.2	05.15	00.00
11. 9.75	75.0	26.9	628.3	05.25	00.00
12. 9.75	76.3	26.6	521.7	02.25	00.00
13. 9.75	75.3	28.1	794.8	09.55	15.49
14. 9.75	76.6	26.9	645.2*	01.75	00.00
15. 9.75	75.3	25.3	697.5	05.55	02.28
16. 9.75	79.2	28.0	652.6	06.90	06.35
17. 9.75	82.0	26.4	632.0	04.30	07.36
18. 9.75	84.7	26.2	630.2	06.26	00.00
19. 9.75	77.5	26.2	696.9	09.20	00.00
20. 9.75	77.9	25.0	655.5*	08.00	00.00

Date	R.H.	T	(Q + q)	S.D.	P
21. 9.75	79.2	26.3	751.7*	09.80	00.00
22. 9.75	84.1	24.6	710.9*	07.35	44.70
23. 9.75	92.3	23.6	379.9*	04.75	37.59
24. 9.75	82.9	27.7	564.4	06.50	00.00
25. 9.75	86.7	24.4	641.9	03.70	25.90
26. 9.75	87.3	24.1	584.9	03.40	12.95
27. 9.75	76.2	26.7	274.4	05.15	00.00
28. 9.75	84.5	23.6	573.6	01.00	03.55
29. 9.75	76.2	26.2	701.6	02.65	04.31
30. 9.75	74.4	26.3	605.9	05.30	00.00
1.10.75	79.4	25.0	755.7	06.45	00.00
2.10.75	72.1	26.5	683.8	06.32	00.00
3.10.75	83.8	25.6	619.2	09.80	00.00
4.10.75	69.4	26.4	729.2*	07.66	00.00
5.10.75	81.2	27.3	560.5*	07.85	00.00
6.10.75	78.7	27.7	558.3*	05.52*	00.00
7.10.75	80.4	26.9	697.2*	06.32*	00.00
8.10.75	80.9	26.6	454.2*	02.06	00.00
9.10.75	75.7	28.4	741.7*	07.65	00.00
10.10.75	70.0	25.6	782.2	10.95	00.00
11.10.75	78.1	28.5	800.7	07.10	00.00
12.10.75	74.9	25.7	743.7	08.00	00.25
13.10.75	74.6	25.1	754.4	08.75	05.84
14.10.75	81.1	27.6	621.1	03.10	00.25
15.10.75	70.1	24.7	732.6	05.90	00.00
16.10.75	91.0	27.3	596.5	05.55	00.50

Date	R.H.	T	(Q + q)	S.D.	P
17.10.75	87.6	26.7	415.1	04.30	13.71
18.10.75	83.9	27.9	598.4	04.30	16.76
19.10.75	81.1	27.3	446.7	01.90	00.00
20.10.75	74.5	25.6	763.2*	07.66	00.00
21.10.75	75.7	26.3	650.8	07.00	00.00
22.10.75	74.0	26.2	619.0	04.30	00.00
23.10.75	71.7	26.6	683.9*	07.30	00.00
24.10.75	77.5	26.3	491.8	00.60	00.00
25.10.75	85.8	24.9	482.5	05.20	31.75
26.10.75	78.6	25.8	678.7*	05.77	11.68
27.10.75	88.2	23.8	387.1	01.90	02.28
28.10.75	83.5	24.8	626.5	05.55	00.00
29.10.75	87.5	24.6	613.4	03.45	05.08
30.10.75	80.7	25.3	706.9	06.65	11.17
31.10.75	92.9	24.2	334.7	01.20	10.92
1.11.75	91.5	24.5	563.9	02.80	58.16
2.11.75	79.5	25.8	375.9	03.75	00.76
3.11.75	78.4	27.7	744.3	02.45	00.76
4.11.75	76.1	26.8	637.7	05.85	00.76
5.11.75	86.6	25.4	596.5	04.70	23.62
6.11.75	87.8	27.3	673.2	06.45	01.77
7.11.75	88.4	25.6	557.3	03.45	60.45
8.11.75	90.3	26.8	578.3	05.20	00.00
9.11.75	94.8	25.6	325.4*	03.35	00.00
10.11.75	86.3	25.8	740.5	08.90	02.54
11.11.75	84.8	25.7	600.3	04.05	00.00

Date	R.H.	T	(Q + q)	S.D.	P
12.11.75	87.5	26.4	813.5	09.50	00.00
13.11.75	82.5	25.1	607.8	05.60	00.00
14.11.75	85.5	25.4	607.8	05.35	03.04
15.11.75	91.1	24.5	493.7	03.55	05.58
16.11.75	86.9	24.6	637.7	05.80	08.63
17.11.75	88.5	26.7	540.2*	04.55	01.01
18.11.75	91.2	25.0	663.9	04.70	23.11
19.11.75	91.3	24.7	510.0*	03.92*	06.85
20.11.75	91.8	24.1	508.6	03.45	08.89
21.11.75	90.2	24.6	556.8	05.07	03.30
22.11.75	96.0	24.1	523.6	00.00	21.08
23.11.75	85.7	25.3	578.4	04.40	17.27
24.11.75	87.2	24.0	295.5	00.00	04.31
25.11.75	91.7	23.8	192.6	00.00	00.00
26.11.75	91.4	26.0	291.7	00.10	06.35
27.11.75	91.2	24.6	244.4	00.00	03.30
28.11.75	92.7	23.2	271.2	08.95	00.76
29.11.75	82.6	25.6	645.9	05.60	00.00
30.11.75	75.3	27.3	755.5	08.95	02.54
1.12.75	79.2	26.3	645.2	08.25	00.00
2.12.75	76.0	26.2	774.2	10.90	00.00
3.12.75	77.5	26.3	781.7	08.85	00.00
4.12.75	76.7	25.2	680.9	06.83	09.90
5.12.75	88.6	24.5	495.8	04.95	06.60
6.12.75	82.3	27.1	577.8	07.15	00.00
7.12.75	82.8	26.8	555.4	06.90	29.71

Date	R.H.	T	(Q + q)	S.D.	P
8.12.75	90.6	24.1	671.3	00.00	82.29
9.12.75	89.5	25.0	573.1	03.30	06.09
10.12.75	83.2	25.9	577.8	04.05	05.08
11.12.75	77.9*	27.4*	633.0*	00.00	00.00
12.12.75	79.3*	26.7*	554.3*	04.45	00.00
13.12.75	82.7*	26.8*	547.3*	04.37*	00.00
14.12.75	86.0*	25.8*	314.2*	01.81*	35.30
15.12.75	80.7*	25.2*	275.4*	01.81*	02.54
16.12.75	81.3*	26.2*	440.1*	01.84*	00.00
17.12.75	84.4*	26.9*	579.1*	04.34*	00.00
18.12.75	70.3*	27.6*	719.5*	08.24*	00.00
19.12.75	76.2	22.8	711.9*	07.12*	01.52
20.12.75	77.5	28.1	589.1	06.30	00.00
21.12.75	83.0	26.2	412.3*	02.44	01.27
22.12.75	78.5	25.9	537.8*	03.79	17.01
23.12.75	79.9	24.6	564.7	06.35	38.60
24.12.75	78.8	21.5	521.7	05.15	32.51
25.12.75	73.9	24.6	680.7	07.00	10.41
26.12.75	69.3	23.4	714.3	10.10	00.00
27.12.75	80.1	23.4	561.0	05.30	07.36
28.12.75	80.4	21.6	463.8	00.00	00.00
29.12.75	78.0	21.9	443.2	00.00	09.14
30.12.75	76.4	23.9	461.9	03.90	06.85
31.12.75	72.0	22.4	555.4	02.10	00.00

Appendix G

Rural-urban Temperature and Humidity Differentials Recorded during the Present Study

Samples of temperature and relative humidity traverses were taken in order to examine the possible effects of the built-up area of Kuala Lumpur - Petaling Jaya upon these two parameters. This Appendix presents temperature and relative humidity differentials (City - Country) for each of the samples. Two types of traverses taken during different times of day (night-time: 2100-2200 hours L.T.; afternoon: 1200-1300 hours L.T.) have been distinguished. For each of these, the data are tabulated thus:

(a) temperature differential (^{o}C)

(b) relative humidity differential (%)

(c) weather condition as indicated by cloud amount and wind speed and is shown thus: 5/2.5 where '5' is cloud amount in octas, and '2.5' is wind speed in ms^{-1}.

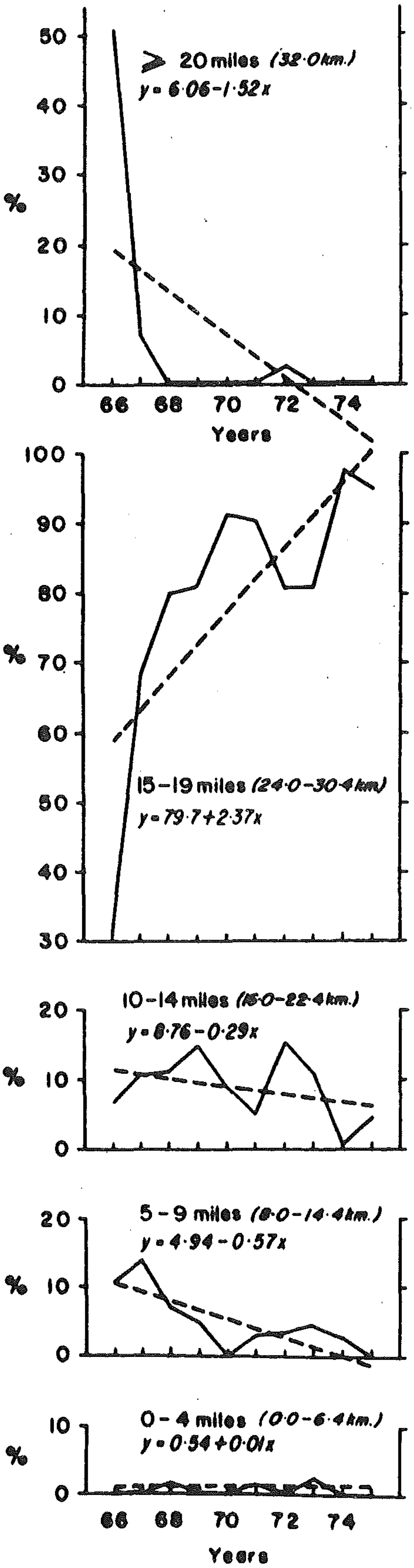
Date	Night-time (2100-2200 hours L.T.)			Afternoon (1200-1300 hours L.T.)		
	(a)	(b)	(c)	(a)	(b)	(c)
3. 8.75	3.4	-18.0	2/0.0	0.8	-06.0	7/3.6
5. 8.75	2.3	-15.0	5/0.0	1.0	-09.0	6/2.2
10. 8.75	-	-	-	1.1	-15.0	7/4.4
12. 8.75	3.0	-10.0	3/0.0	1.7	-11.0	6/4.2
15. 8.75	2.4	-13.0	5/0.0	-	-	-
22. 8.75	3.5	-17.0	1/0.0	0.3	-08.0	7/3.0
25. 8.75	3.6	-18.0	1/0.0	0.4	-07.0	7/3.3
29. 8.75	1.5	-07.0	6/0.0	1.2	-07.0	6/1.3
3. 9.75	1.4	-08.0	6/0.0	1.7	-08.0	7/1.7
10. 9.75	2.9	-09.0	2/0.0	-	-	-
16. 9.75	-	-	-	1.0	-05.0	6/1.6
18. 9.75	2.5	-14.0	5/0.0	0.7	-03.0	7/4.0
4.10.75	3.8	-16.0	3/0.0	-	-	-
9.10.75	3.2	-11.0	3/0.0	0.6	-05.0	6/0.4
2.11.75	2.9	-15.0	5/0.0	-	-	-
4.11.75	2.0	-09.0	6/0.0	0.4	-05.0	7/0.3
5.11.75	2.0	-04.0	6/0.0	0.6	-06.0	6/2.2
10.11.75	2.8	-20.0	5/0.0	0.9	-05.0	7/3.0
15.11.75	2.8	-12.0	6/0.0	-	-	-
18.11.75	1.5	-05.0	7/0.0	0.5	-09.0	7/1.3
21.11.75	1.2	-10.0	7/0.0	-	-	-
25.11.75	2.8	-15.0	4/0.0	-	-	-

Date	Night-time (2100-2200 hours L.T.)			Afternoon (1200-1300 hours L.T.)		
	(a)	(b)	(c)	(a)	(b)	(c)
27.11.75	2.0	-08.0	6/0.0	0.4	-05.0	6/0.4
30.11.75	2.4	-13.0	6/0.0	-	-	-
3.12.75	5.0	-15.0	1/0.0	0.3	-10.0	5/3.3
6.12.75	2.3	-06.0	3/0.0	0.3	-04.0	7/3.5
14.12.75	4.4	-19.0	2/0.0	-	-	-
24. 6.76	5.1	-14.0	3/0.0	-	-	-
25. 6.76	2.0	-09.0	5/0.0	-	-	-
28. 6.76	5.0	-11.0	2/0.0	-	-	-
3. 7.76	4.6	-10.0	3/0.0	-	-	-
11. 7.76	2.8	-15.0	5/0.0	-	-	-
12. 7.76	3.2	-12.0	2/0.0	-	-	-
15. 7.76	4.1	-13.0	2/0.0	-	-	-
18. 7.76	5.5	-15.0	3/0.0	-	-	-

Appendix H

The Percentage Frequencies of Visibilities in Given Ranges, by Month, during the 1966-75 Decade and the Schematic Shifts of Visibility Frequency Changes with Wind Directions in the Sector 35°-135° at Subang Airport

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

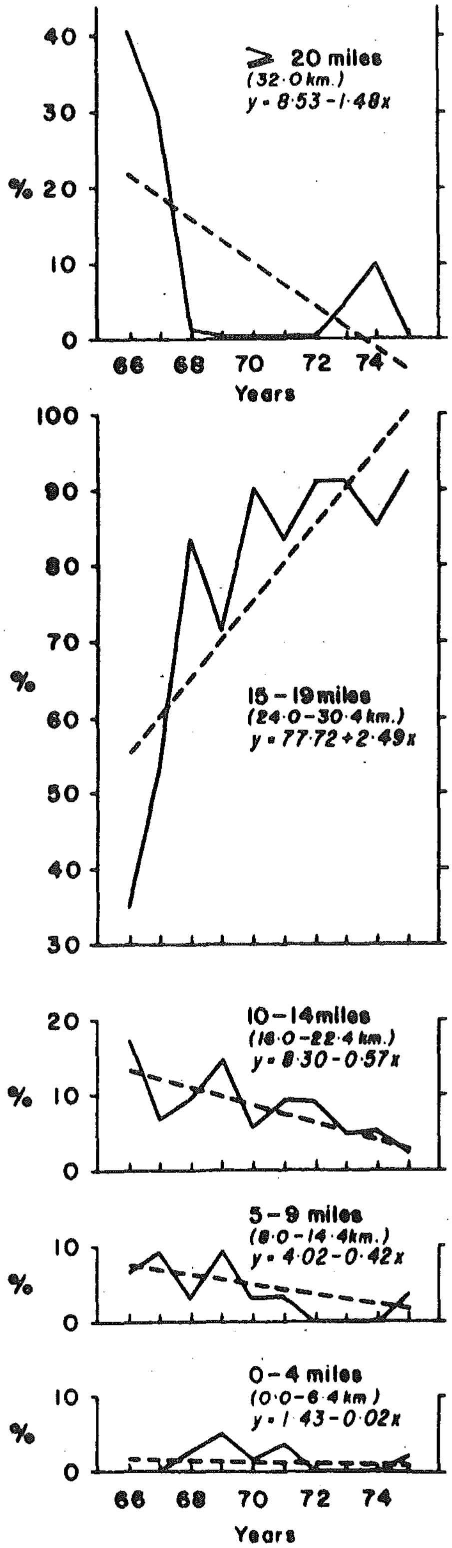


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES	
19·7	−7·6	−27·3 +	0	=	−27·3
58·4	101·0	+42·6 +	−27·3 −15·3	=	0
11·4	6·2	−5·2 +	−10·1	=	−15·3
10·0	−0·2	−10·2 +	+0·1	=	−10·1
0·5	0·6	+0·1 +	0	=	+0·1

January

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

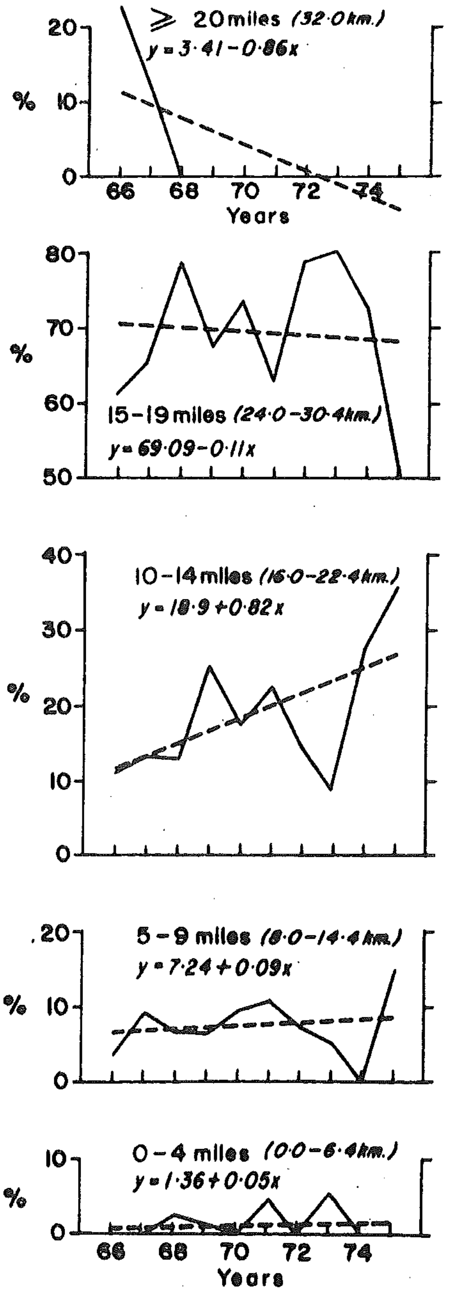


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75		FLUX OF RESULTAN CHANGES		
21·9	−4·8	−26·7	+	0	=	−26·7
55·3	100·1	+44·8	+	−26·7 −18·1	=	0
13·4	3·2	−10·2	+	−7·9	=	−18·1
7·8	0·2	−7·6	+	−0·3	=	−7·9
1·6	1·3	−0·3	+	0	=	−0·3

February

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

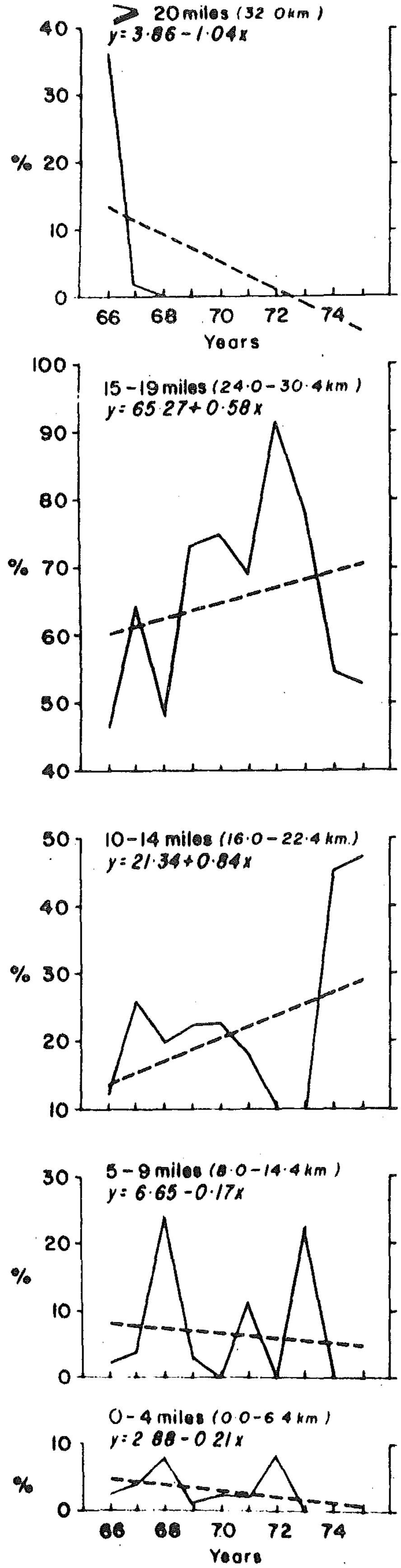


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75		FLUX OF RESULTAI CHANGES	
11·1	-4·3	-15·4	+	0	= -15·4
70·1	68·1	- 2·0	+	-15·4	= -17·4
11·5	26·3	+ 14·8	+	-17·4	= -2·6
6·4	8·1	+ 1·7	+	-2·6	= -0·9
0·9	1·8	+ 0·9	+	-0·9	= 0

March

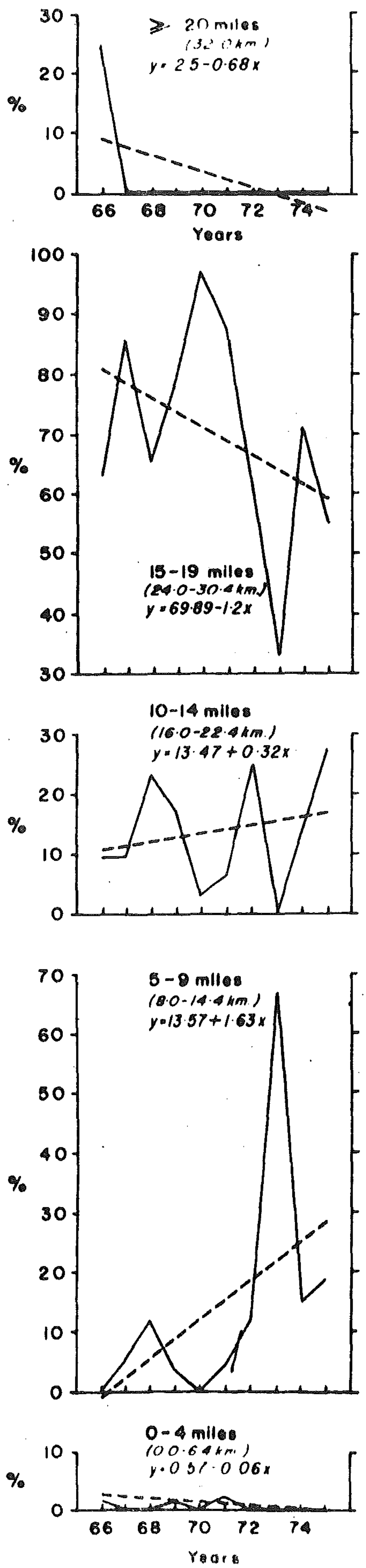
PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE



FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75	FLUX OF RESULTAN CHANGES
13·2	-5·5	-18·7 + 0	= -18·7
60·1	70·5	+10·4 + -18·7	= -8·3
13·8	28·9	+15·1 + -8·3 / -6·8	= 0
8·2	5·1	-3·1 + -3·7	= -6·8
4·7	1·0	-3·7 + 0	= -3·7

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

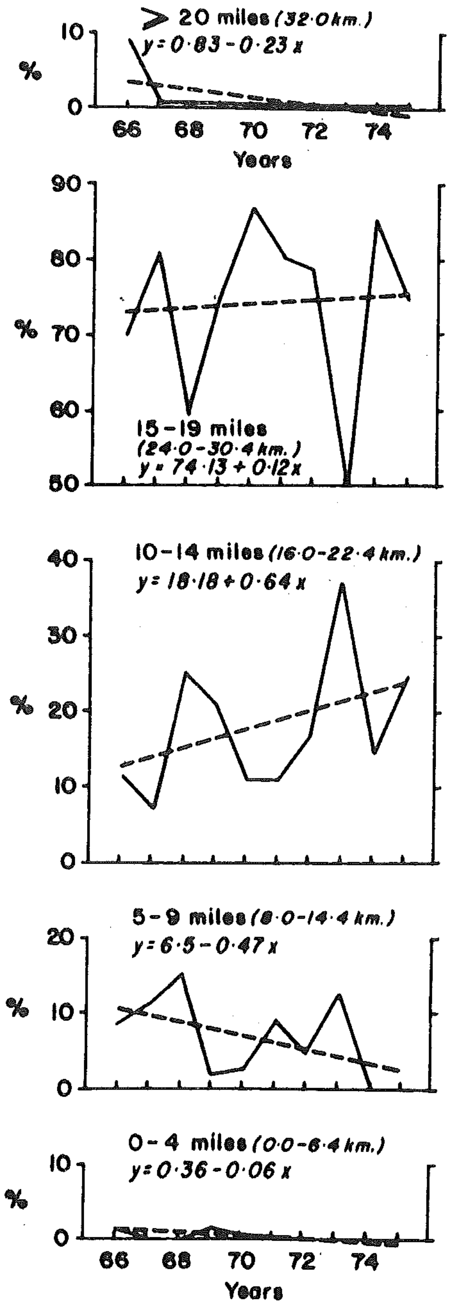


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES		
8·6	-3·6	-12·2	+	0	=	-12·2
80·7	59·1	-21·6	+	-12·2	=	-33·8
10·6	16·3	+5·7	+	-33·8	=	-28·1
-1·1	28·1	+29·2	+	-28·1 -1·1	=	0
1·1	0·0	-1·1	+	0	=	-1·1

May

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

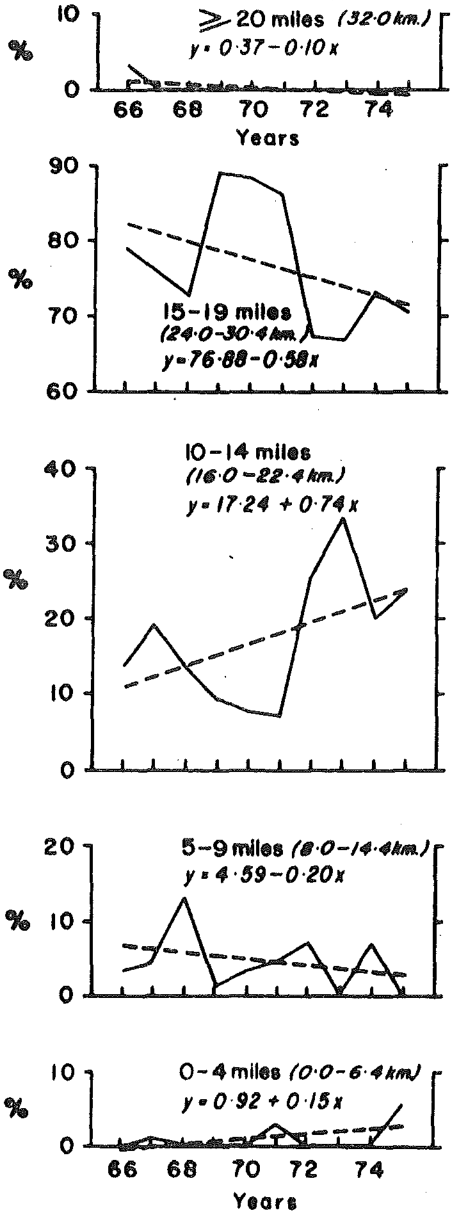


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75				FLUX OF RESULTAN CHANGES
2·9	−1·2	−4·1	+	0	=	−4·1
73·1	75·2	+2·1	+	−4·1	=	−2·0
12·4	23·9	+11·5	+	−2·0 −9·5	=	0
10·7	2·3	−8·4	+	−1·1	=	−9·5
0·9	−0·2	−1·1	+	0	=	−1·1

June

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

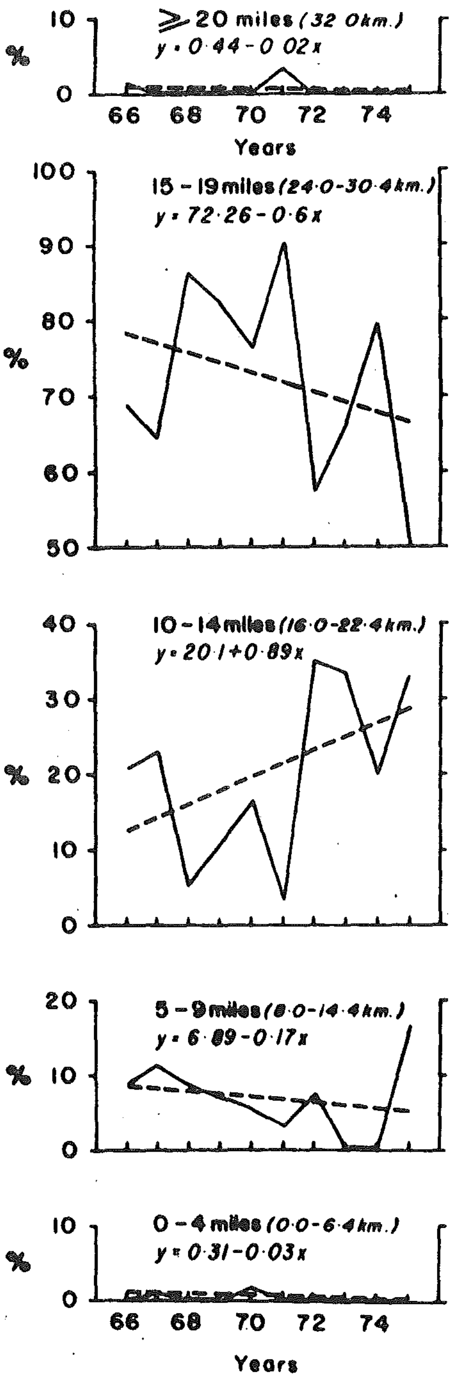


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES		
1·3	−0·5	−1·8	+	0	=	−1·8
82·1	−71·6	−10·5	+	−1·8	=	−12·3
10·6	23·9	+13·3	+	−12·3 −1·0	=	0
6·4	2·8	−3·6	+	+2·6	=	−1·0
−0·4	2·2	+2·6	+	0	=	+2·6

July

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

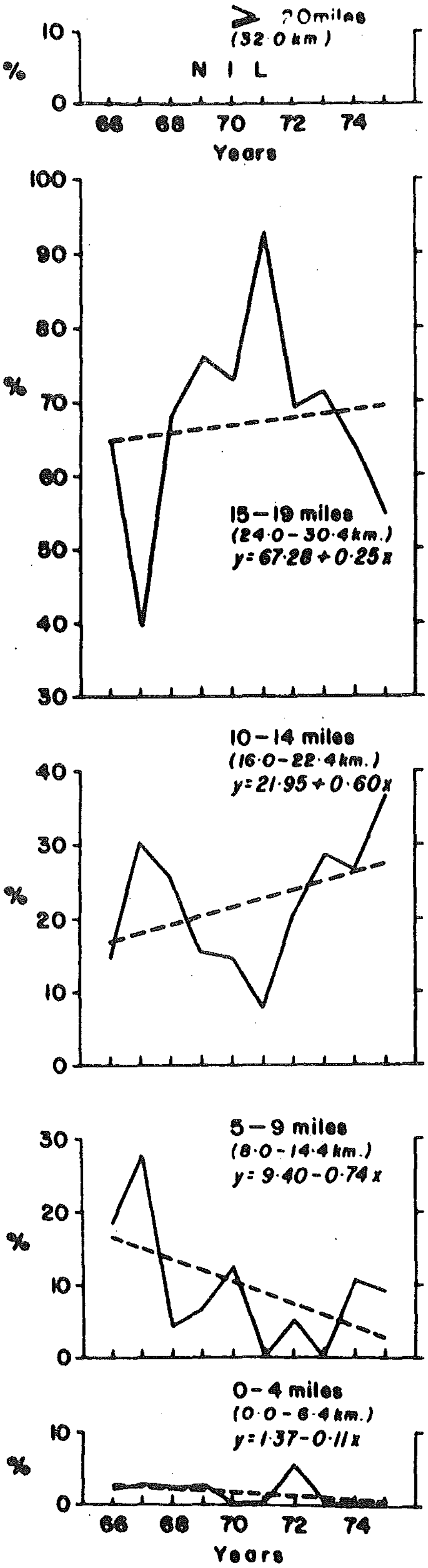


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75		FLUX OF RESULTAN CHANGES		
0·6	0·3	−0·3	+	0	=	−0·3
78·3	66·2	−12·1	+	−0·3	=	−12·4
12·1	28·1	+16·0	+	−12·4 −3·6	=	0
8·4	5·4	−3·0	+	−0·6	=	−3·6
0·6	0·0	−0·6	+	0	=	−0·6

August

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

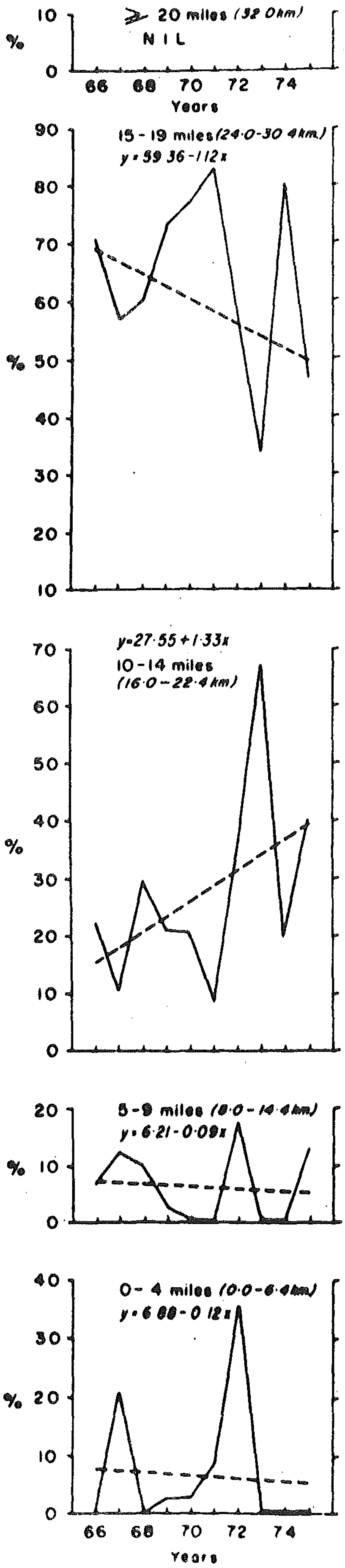


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES
0.0	0.0	N I L		
65.0	69.6	+ 4.6 +	– 4.6	= 0
16.6	27.4	+ 10.8 +	– 15.4	= – 4.6
16.1	2.7	– 13.4 +	– 2.0	= – 15.4
2.4	0.4	– 2.0 +	0	= – 2.0

September

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

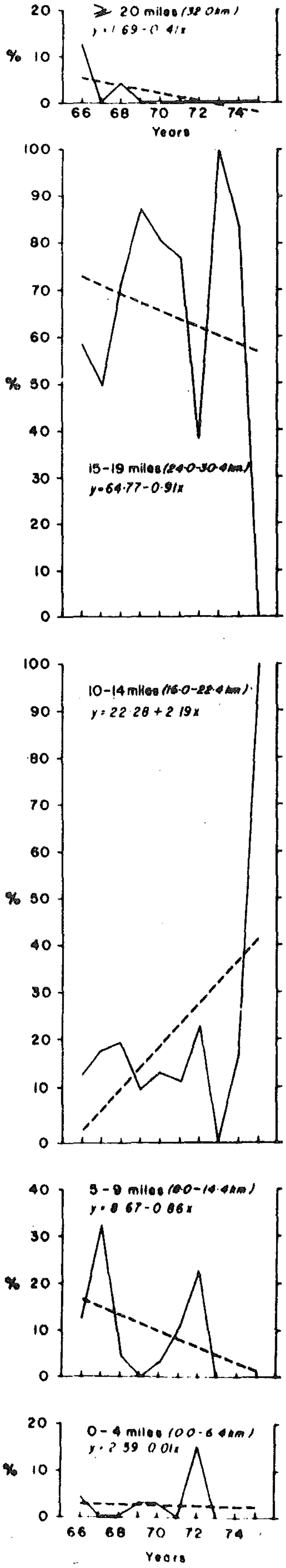


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75	FLUX OF RESULTANT CHANGES
0 0	0 0	NIL	
69·4	49·3	-20·1	+ 0 = -20·1
15·6	39·5	+23·9	+ -20·1 -3·8 = 0
7·0	5·4	-1·6	+ -2·2 = -3·8
8·0	5·8	-2·2	+ 0 = -2·2

October

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE

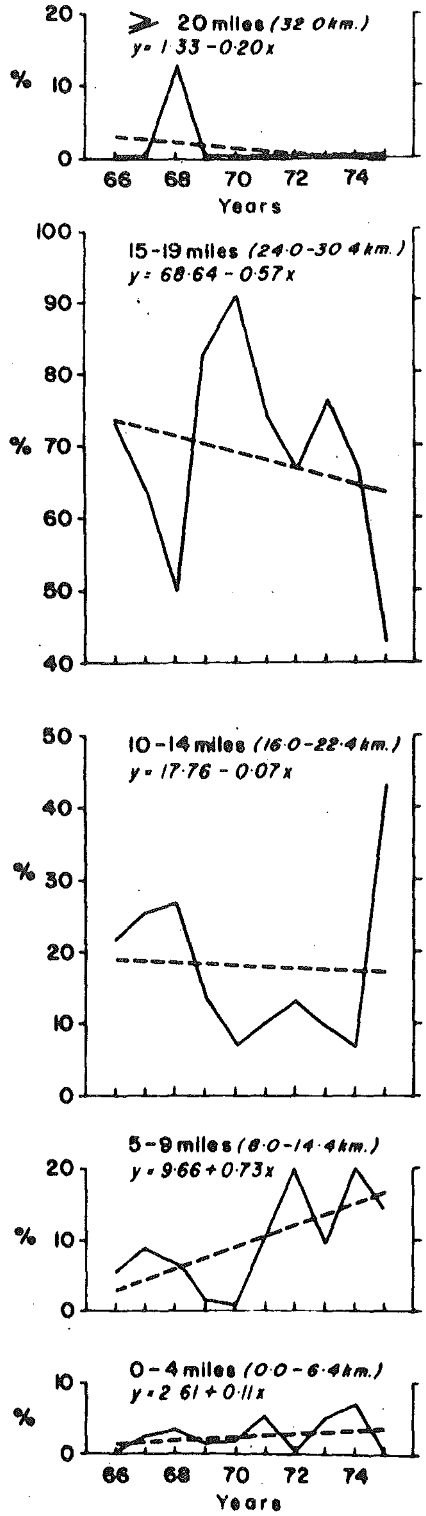


FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	1975	NET CHANGE 66 75		FLUX OF RESULTANT CHANGES		
5.4	-2.0	-7.4	+	0	=	-7.4
73.0	56.6	-16.4	+	-7.4	=	-23.8
2.5	42.0	+39.5	+	-23.8 -15.7	=	0
16.4	0.9	-15.5	+	-0.2	=	-15.7
2.7	2.5	-0.2	+	0	=	-0.2

November

PERCENT FREQUENCIES OF VISIBILITIES IN GIVEN RANGES BY YEARS WITH LINEAR TREND LINE



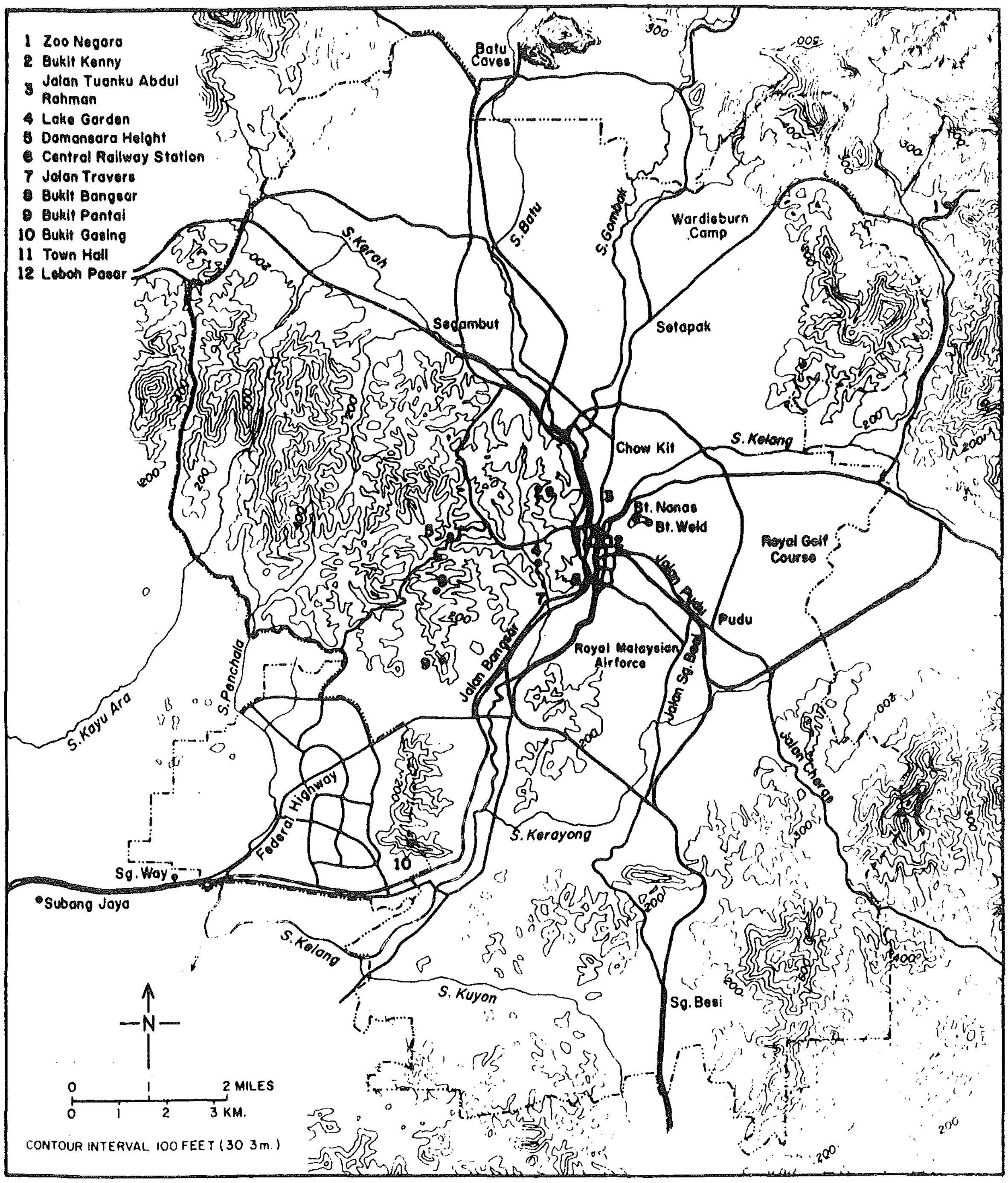
FLUX OF VISIBILITY FREQUENCY CHANGES

FREQUENCY 1966	FREQUENCY 1975	NET CHANGE 66 75	FLUX OF RESULTA CHANGES
3·1	−0·5	−3·6 + 0	= −3·6
73·8	63·5	−10·3 + −3·6	= −13·9
18·4	17·1	−1·3 + −13·9	= −15·2
3·0	16·2	+13·2 + −15·2	= −2·0
1·6	3 6	+2·0 + −2·0	= 0

December

Appendix I

Map of Kuala Lumpur - Petaling Jaya
showing place names mentioned in text



Kuala Lumpur - Petaling Jaya